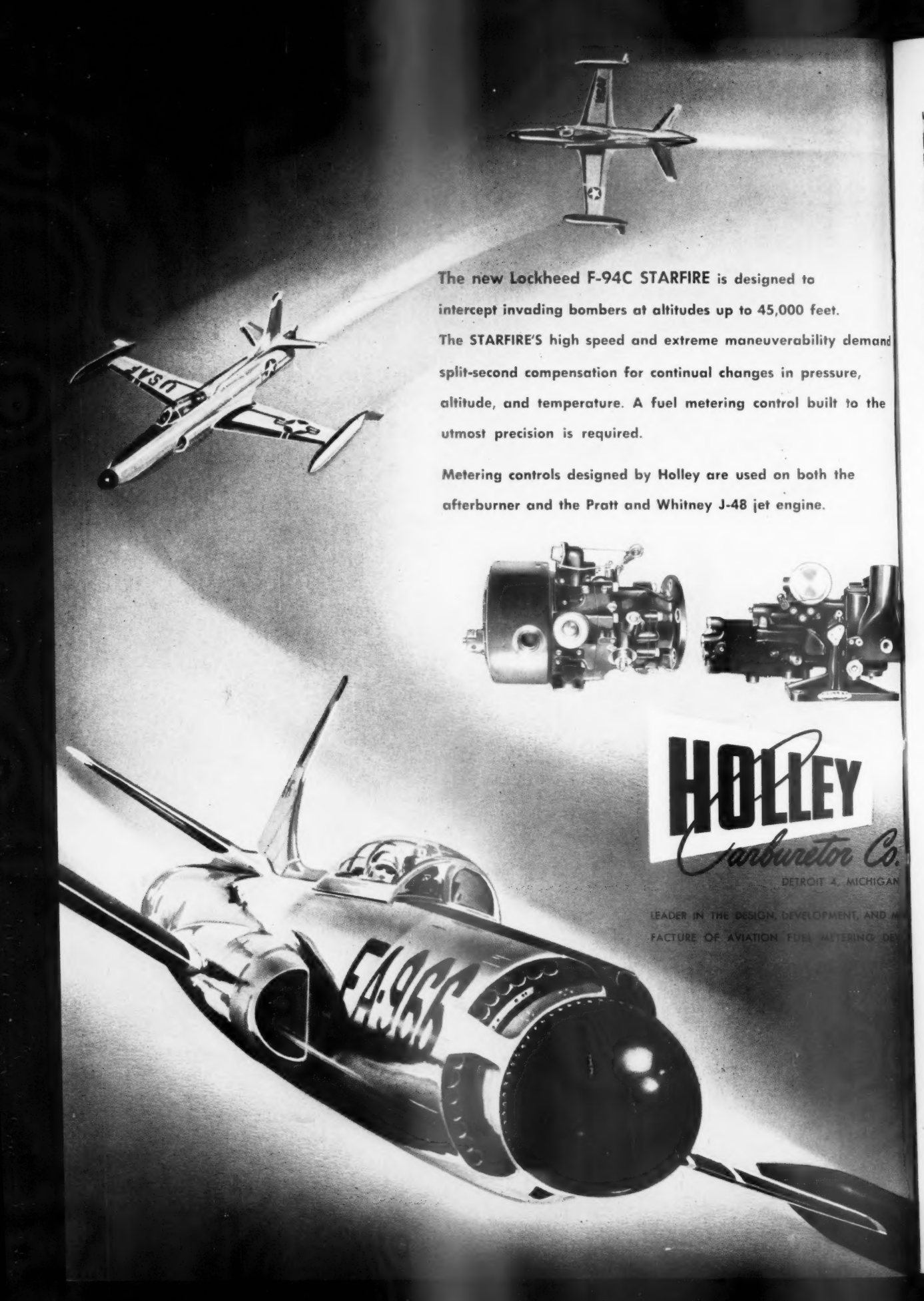
AERONAUTICAL ENGINEERING REVIEW

NOVEMBER 1952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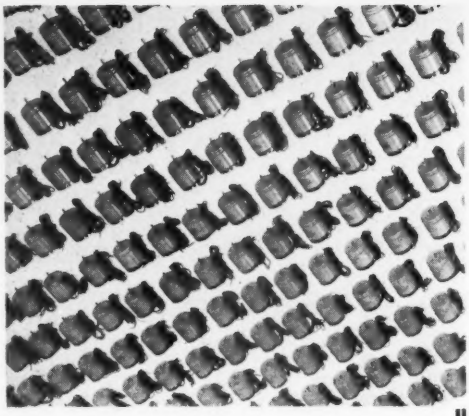
HOLLEY
Carburetor Co.
DETROIT 4, MICHIGAN
LEADER IN THE DESIGN, DEVELOPMENT, AND M
FACTURE OF AVIATION FUEL METERING DE



Cover—These tiny motor-like Autosyn Synchros are manufactured by the Eclipse-Pioneer Division of Bendix Aviation at the rate of one every 20 sec. to meet the requirements of modern aviation. These small "nerve-centers" are used literally by the hundreds in the remote indicating and control systems of today's aircraft.

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AERONAUTICAL ENGINEERING REVIEW

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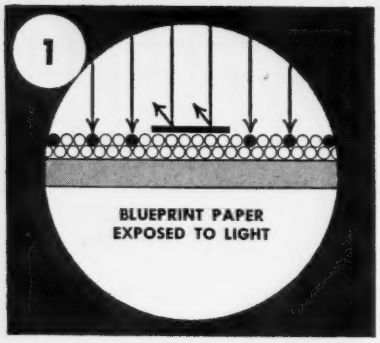
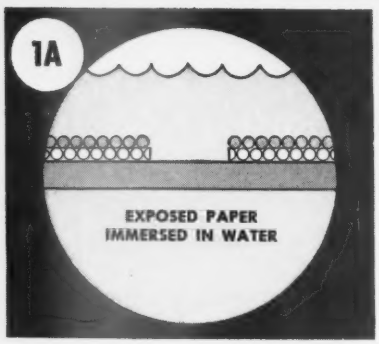
Why is a blueprint



Simplified diagram of enlarged cross section of blueprint paper shows surface particles of the coating being struck by light. The coating, which is pale in color, contains two soluble ferric salts: a cyanide complex and an organic acid. Light reduces some of the ferric to ferrous ions in the exposed areas, producing a mixture of both. Opaque lines in a superimposed drawing prevent the light from reaching the coating beneath, as shown by the black bar in the center.



In the presence of water, the ferrous ions in the exposed areas react with the cyanide complex to form a ferrous-ferricyanide, which is Prussian Blue. (This is the famous blue pigment, insoluble in water, discovered in Berlin in 1704.) The areas that were shielded from light contain only the original soluble salts. These are washed away by the water, exposing the white paper beneath. The print then has white lines on a blue background.

Contrary to ordinary photographic processes, moderate overexposure of a blueprint has two good effects. It permits light to penetrate beneath the surface of the coating and thus to act in depth. It also reduces more of the surface salts from the ferric to ferrous condition, including the cyanide complex. But carried to an extreme, overexposure causes light to penetrate the opaque lines of a drawing with a resultant loss of contrast in the developed print.

I. A. S. News

A Record of People and Events of Interest to Institute Members

I.A.S. Twenty-First Annual Meeting

THE TWENTY-FIRST ANNUAL MEETING of the Institute of the Aeronautical Sciences will be held during the week of January 26, 1953, at the Hotel Astor in New York. It is interesting to note that, coincidentally with the opening date of this meeting, the Institute completes two decades of service to the aeronautical profession and embarks upon a third. It was at the I.A.S. Founders' Meeting at Columbia University on January 26, 1933, that the Institute held the first two technical sessions in its history.

The Institute has adopted the policy of presenting some of the technical sessions during the annual meeting in cooperation with several other societies. Accordingly, certain sessions, such as those on meteorology and rotating wing, will be given jointly, while other sessions—e.g., those on aerodynamics and design—will be an I.A.S. presentation only.

Electronics in aviation and aviation medicine are among those subjects that are to be discussed at the forthcoming annual meeting. Twenty years ago, neither of these subjects played a really serious role in aeronautical engineering, their inclusion at that time being somewhat analogous to our preparing at this moment for an immediate trip to another planet.

Dr. Edward Warner

Electronics in aviation, a comparatively recent addition to the aeronautical sciences, has become so important in aeronautical engineering that it is virtually impossible for high-speed flight to be carried on without it. The Institute, recognizing this growing relationship between electronics and aviation, began 2 years ago to devote an entire day (rather than a single session), during the annual meeting to electronics in aviation. This year, for the third successive annual meeting, a full day will be given over to this subject. As in the past, the program will be presented by the I.A.S. in cooperation with the Institute of Navigation, Institute of Radio Engineers, and Radio Technical Committee for Aeronautics.

Because of the unqualified interest engendered by previous symposiums on electronics in aviation, the members of the Electronics in Aviation Committee, who represent the participating societies, resolved to devote the morning session to the presentation of technical papers and the afternoon and evening sessions to a symposium.

Dr. Edward Warner, President of the I.C.A.O. Council, will act as moderator of the symposium, which will be entitled "Electronic Control and Stabilization of Aircraft." The panel members were selected by the committee so as to ensure adequate representation of the operational, electronic, and aerodynamic phases of the problem.

On another day of the Twenty-First Annual Meeting, one of the technical sessions will be on an aeromedical theme. The session will be conducted by the U.S.A.F. School of Aviation Medicine under the chairmanship of its Commandant, Brig. Gen. Otis O. Benson, Jr., U.S.A.F. (M.C.). Under the general topic of "Aeromedical Problems of Air Transportation of This Next Decade," it is planned to offer approximately eight aeromedical papers "roughly" entitled: (1) Trends and Transition in Aeromedical Problems with a View Toward the Next Ten Years; (2) The Atmospheric Phenomena of Greatest Human Significance in the Flying of the Next Decade; (3) Pressurization Requirement, Explosive Decompression, and Protective Measures; (4) Vision at High Speed and High Altitude; (5) The Problems of Noise in Air Transport and in Ground Operations; (6) Aeromedical Problems of Nuclear Fission Propulsion; (7) The Problem of Deceleration and Crash Protection; and (8) The Toxicological Problems of Modern Aviation.

The I.A.S. Annual Business Meeting will be held during the afternoon of Wednesday, January 28. The printed program, containing complete information on the Twenty-First Annual Meeting, should be in the hands of I.A.S. members around the first of the coming year.

Brig. Gen. Otis O. Benson, Jr.

Two New Corporate Members

The Corydon M. Johnson Company, Inc., and Loewy Construction Company, Inc., have become Corporate Members of the Institute of the Aeronautical Sciences.

The Corydon M. Johnson Company, of Bethpage, L.I., N.Y., has been engaged in the preparation of engineering drawings, design data, and technical publications for over 20 years. Within the last 10 years, the company has extended its services to include creative printing and a complete advertising service. The Johnson Company serves the ever-growing industrial and business establishments on Long Island. These include such firms as Grumman, Kenyon, Fairchild, Sperry, Republic, Flight Refueling, Aero Supply, Telephonics, etc., which have need of drawings, reports, instruction books, brochures, advertising, sales literature, catalogs, charts, and other data.

The Johnson Company now employs a staff of approximately 170 trained personnel, including engineers (aeronautical, mechanical, electronic), draftsmen, writers, artists, illustrators, photo technicians, typographers, lithographers, and printers.

This firm, managed by Corydon M. Johnson who founded the business in early 1931, has grown steadily through the years to its present position in the fields of aircraft and electronics. For the past 5 years, the company has published what is known throughout the east as the "Corydon M. Johnson Report." This report is a summary of significant developments in Long Island's industry and business and is prepared each month to be circulated privately to key executives.

Loewy Construction Company, Inc., and its parent company, Hydropress, Inc., are engineers and manufacturers of heavy industrial equipment for plastic forming of metals. Their activities cover two major groups of equipment, with particular emphasis on the needs of the aeronautical industry:

(1) Hydraulic equipment, including vertical and horizontal presses for extrusion, forging, upsetting, piercing, deep-drawing, and other forming of metals; and hydraulic machines for production testing of pipe, upsetting of pipes and couplings, heavy push benches, etc.

(2) Rolling mill equipment for all metals and purposes—from heavy blooming mills to high-precision foil mills, taper sheet mills, roll forging machinery, etc., and including auxiliary equipment such as roller tables, cooling beds, shears, and saws.

The Industrial Engineering Department of Loewy Construction Company accepts assignments on research and development of new methods of plastic forming of metals in addition to the engineering of complete industrial plants. Their engineering covers specialized departments—e.g., forging shops, extrusions shops—or complete manufacturing plants for producing air-frame parts, etc.

At present, Loewy Construction Company is engaged in designing and supplying super-heavy presses for the U.S.A.F.'s Heavy Press Program.

Manly Medal Winners

Joseph M. Mergen (M.) (left), Chief Design Engineer, and Jack H. Kasley (M.) (right), Chief Aerodynamics Engineer, Curtiss-Wright Corporation's Propeller Division, are the recipients of the 1952 Manly Memorial Medal. This medal, sponsored by the Society of Automotive Engineers, was won by the Messrs. Mergen and Kasley for their technical paper on "Characteristics of Propellers for Turboprop Airplanes." Presentation of the award was made on October 3 during the S.A.E. National Aeronautic Meeting held in Los Angeles.

Erratum

1952 Guggenheim Medalist

Through a series of errors, a picture of the late Geoffrey de Havilland appeared in this magazine instead of one of his father, Sir Geoffrey de Havilland, Technical Director of The de Havilland Company, Ltd., of England. This picture was used on page 18 of the October, 1952, issue of the REVIEW in connection with the announcement of the "1952 Guggenheim Medalist." The Editors of this magazine regret any embarrassment that this may have caused.

As the winner of the 1952 Guggenheim Medal, Sir Geoffrey has been cited for "forty years of pioneering in military and commercial aircraft and the development of long-range jet transport." This award will be presented to Sir Geoffrey at the forthcoming Annual Meeting of The American Society of Mechanical Engineers, which will be held at the Hotel Statler in New York from November 30 to December 5.

American Helicopter Society News

Harry Lounsbury, new Executive Secretary of the American Helicopter Society, is now at work at the A.H.S. home office in the Institute of the Aeronautical Sciences' New York building, where he is beginning to tackle the myriad details of his position.

Of prime importance to all of us in the society is, of course, the matter of increasing our present membership in order to keep the organization a going concern. To this end, Harry is preparing a history of the society to be incorporated in a new brochure that will be available to potential new members. When the society has something concrete of this type to offer a prospective American Helicopter Society member, it is reasonable to assume that more interest in the organization will be generated. It is hoped that such a brochure will be ready for distribution in the near future.

It is Harry Lounsbury's intention as a new member of our staff to meet personally as many of our people as possible in the near future. This will give him the opportunity to obtain a better understanding of the details of the society in order that he may be in

a better position to offer his services to the membership.

▸ Under an agreement with the Helicopter Association of Great Britain, A.H.S. has supplied the British organization with three copies of each of the Forum Proceedings from 1947 through 1952. In return, A.H.S. is to receive a file of the Journal of the British association which will be put in the library of the Institute of the Aeronautical Sciences. The exchange program will be continued in the future.

CLAUDE O. WITZE
Publicity Chairman, A.H.S.

News of I.A.S. Members

▸ **Colonel Robert J. Benford,** U.S.A.F. (M.C.) (A.F.), Associate Editor, U.S. Armed Forces Medical Journal, has been named a member of the Institute's Editorial Committee on Physiologic Problems, succeeding the late Col. Arnold D. Tuttle, U.S.A. (Ret.) (M.), Medical Director of United Air Lines, Inc. Colonel Benford is also a member of the Advisory Editorial Board of the Journal of Aviation Medicine.

▸ **Willy Ley** (M.) has joined the faculty of the Fairleigh Dickinson College and is presenting a technical course on rocketry in the evenings for the current scholastic year.

▸ **Dr. Angelo Miele** (M.) has been appointed full-time Assistant to Prof. Antonio Ferri (A.F.), Department of Aeronautical Engineering, Polytechnic Institute of Brooklyn. Dr. Miele is on leave of absence from his position as Professor of Mechanics and Assistant Professor of Aerodynamic Design, Escuela de Aviacion Militar, Escuela Superior de Aerotécnica, University of Córdoba, Córdoba, Argentina, S.A.

▸ **George W. Papen** (M.), Department Manager, Production Engineering Department, Lockheed Aircraft Corporation, has been preparing a questionnaire under a project for the Aircraft Research and Testing Committee, Aircraft Industries Association of America, to investigate requirements and potentialities for improved aircraft castings.

▸ **Igor I. Sikorsky** (H.F.), Engineering Manager, Sikorsky Aircraft Division, United Aircraft Corporation, is the recipient of the National Defense Transportation Association's annual award for significant contribution to defense transportation.

▸ **J. Parker Van Zandt** (F.), for whose services a request was made to the Secretary of the Air Force by the International Civil Aviation Organization, is now making a survey abroad under the Technical Assistance Program. He will return to this country sometime this next year. Mr. Parker has been serving as Deputy for Civil Aviation in the Office of the Secretary of the Air Force.

▸ **Theodore P. Wright** (H.F.), Vice-President for Research, Cornell University, has joined the Aircraft Production Board on a temporary basis to serve as a consultant on the board's study, or "Campbell report," on aircraft production.

Members on the Move

The purpose of this section is to provide information concerning the latest affiliations of I.A.S. members. All members are, therefore, urged to notify the News Editor of changes as soon as they occur.

H. Norman Abramson (T.M.), Acting Associate Professor of Aeronautical Engineering, The Agricultural and Mechanical College of Texas. Formerly, Project Analytical Engineer, Chance-Vought Aircraft Division, United Aircraft Corporation.

Malcolm J. Abzug (M.), Design Specialist, Aerodynamics Section, El Segundo Plant, Douglas Aircraft Company, Inc.

Company Officer

J. P. Donald Garges (A.F.) was recently appointed Vice-President—Engineering and Assistant General Manager of East Coast Aeronautics, Inc., a subsidiary of Barium Steel Corporation. Prior to this appointment, he had been East Coast's Chief Engineer since 1948. Before joining the company, Mr. Garges served as Chief Engineer for Fairchild Engine and Airplane Corporation's Personal Planes Division and for General Motors Corporation's Eastern Aircraft Division

Formerly, Project Engineer, Flight Controls Department, Sperry Gyroscope Company, Division of The Sperry Corporation.

Ray B. Anderson (T.M.), Engineer, Stress Group, El Segundo Plant, Douglas Aircraft Company. Formerly, Lieutenant (j.g.), U.S.N., Bureau of Aeronautics, Department of the Navy, Washington, D.C.

Second Lieutenant Stanley H. Apte, U.S.A.F. (T.M.), Project Officer of the Lockheed Office, Fighter Section, Procurement Division, Air Materiel Command, Wright-Patterson Air Force Base, Ohio. Formerly, Stress Analyst, Republic Aviation Corporation.

Parker M. Bartlett (M.), Field Engineer, Aero Engineering, Inc. Formerly, Power Plant Division, Bureau of Aeronautics, Department of the Navy, Washington, D.C.

Guy E. Beardsley, Jr. (A.F.), Development Engineer in Charge of Atomic Energy Project, Pratt & Whitney Aircraft Division, United Aircraft Corporation. Formerly, Development Engineer, Pratt & Whitney.

Second Lieutenant Robert B. Benjamin, U.S.A.F. (T.M.), on Extended Active Duty, Air Force. Formerly, Aeronautical Engineer (Dynamic Loads), Civil Service, Wright-Patterson A.F.B., Ohio.

Dr. Bruno A. Boley (M.), Associate Professor of Civil Engineering, Aeronautical Structures Laboratory, School of Engineering, Columbia University. Formerly, Assistant Professor of Aeronautical Engineering, The Ohio State University.

Thomas E. Bolner (T.M.), Graduate Student, School of Engineering, University of Missouri. Formerly, Design Draftsman, Experimental Laboratory, Warner Gear Division, Borg-Warner Corporation.

Commander Larry L. Booda, U.S.N. (A.M.), Executive Officer, Naval Air Reserve Training Unit, Naval Air Station, Anacostia, D.C. Formerly, Head, Aviation Periodicals Section, Naval Aviation News, The Pentagon, Washington, D.C.

A. A. Boon Hartsinck (M.), Management and Financial Consultant, 2194 Broadway, Redwood City, Calif. Formerly, with Hiller Helicopters.

Robert W. Bradham (M.), Power Plant Design Group Engineer, Helicopter Division, Bell Aircraft Corporation. Formerly, Head of Research and Development, Power Plant Design Staff, The Glenn L. Martin Company.

Miguel E. Bustamante, Jr. (T.M.), Junior Maintenance Engineer, Cia. Mexicana de Aviacion, S.A., Mexico, D.F., Mexico. Formerly, Private First Class, U.S.M.C., Engineer, Marine Air Corps Air Station, Cherry Point, N.C.

George C. Carver (T.M.), Structures Test Engineer, Chance Vought Aircraft Division of United Aircraft Corporation. Formerly, Junior Production Liaison Engineer, Chance Vought.

Richard P. Castle (T.M.), Design Engineer, Consolidated Vultee Aircraft Corporation. Formerly, Designer-Draughtsman, A. V. Roe Canada, Ltd.

(*Continued on page 65*)

Editorial

Fall Forecast

Although the Institute's official report of condition does not appear until the March issue of the REVIEW, the closing of our fiscal year on September 30 gives us a chance to make a preliminary estimate of how things are going and provides your management with the necessary "weather" data on which to base a "flight plan" for the current year. Our final audited report for the year will show that, after ploughing back substantial amounts to increase all I.A.S. services and in spite of continually increasing costs for goods and services, we have lived well within our income and have been able to lay away a little to help tide over possible slack periods in the future.

The real gage of an organization such as ours, however, lies not in its financial statement but in the *quality* of its membership. The "who's who" of the Roster is of much greater importance than the "how many." On that score we are on solid ground. The men who are the I.A.S. are the men whose untiring efforts in research, design, and management are building a solid foundation for American Air Power. They represent a real cross section of leadership in all branches of the aeronautical sciences.

Nor are we doing too badly numberwise. We have never put on any national campaigns to increase our membership. We feel that the activity generated in the twenty-odd local Sections of the Institute is the best inducement to join the organization. Year by year in spite of a modest turnover in the lower grades of membership (caused mainly by financial stress or transfer to other occupation), our total enrollment has grown steadily to a figure now approaching 9,000. More important—of this total, over 85 per cent are now participating in organized Section activities. We are firmly convinced that the real strength of the Institute lies in its local Sections. No amount of "pumping up" from national headquarters can keep this organization alive and progressive unless the local organizations are alive and progressive. We are indeed fortunate in this respect. In our visits to the various Sections in all parts of the North American continent, a high level of interest and participation in Institute affairs is in evidence. Not only are I.A.S. sections carrying out the basic mission of interchange of technical information among our members, but more and more they are realizing that they have an obligation to take some active part in community aviation affairs. Through carefully planned programs they are improving "public relations" in the best sense of the term and are also undertaking a certain amount of vocational guidance through I.A.S. Student Branches in their areas and at the high-school level. The national organization is doing all it can to support such activities, not only from a financial standpoint but through a newly organized information service whereby section officers are constantly kept posted on plans and programs of all other I.A.S. Sections.

In this connection we have been particularly pleased by the high level of the programs announced for the coming year by I.A.S. Sections. In most cases the topics that have been selected and the speakers who have been secured are of the same caliber as for our national meetings. We take this occasion to congratulate our Section and local Program Chairmen for the excellent jobs they are doing.

There is little need to point out to REVIEW readers that Institute publications are bigger and better. (The "bigger" is a physical fact that anyone can determine by a page count. We use the word "better" in all modesty, based entirely on the evidence of written and verbal reports that have been received by your Editor!) As a matter of fact, our financial report for the year shows that a substantial portion of the surplus which has been laid aside for future I.A.S. operations has been generated by the REVIEW. The high quality and general usefulness of its editorial content has built up a readership (both in quality and in quantity) which is extremely attractive to the important advertisers in

this industry. They find that they cannot afford to stay out of the REVIEW (Advt.!). By supporting Institute publications they find that they not only do a good job for themselves but at the same time lend their financial support to its many activities.

Our associations with our related technical societies have never been better. We are fully committed to a policy of cooperation and collaboration with all groups that are making contributions in our field of interest, as a glance at any of our national meeting programs will show. Also, at the Section level, we are encouraging joint activity whenever the advancement of the arts and sciences of aeronautics is thereby better served.

The cooperation that we have been receiving from the Armed Services and other Government agencies has been excellent. All the defense agencies have been most generous in extending invitations to I.A.S. groups to visit facilities and to participate in special programs. The large number of individual members from the Air Force, the Navy, and civilian branches (as indicated by the current ROSTER) is an indication of the esteem in which our organization is held in Government circles.

We believe, on the whole, that I.A.S. members, both, individual and corporate, are getting their money's worth in services rendered, we do not feel that anyone should belong to this organization on the grounds of personal prestige or professional standing alone. We are not seeking "contributions." We are all striving to produce real returns to all our members of all professional grades. We believe we are succeeding.

For the Fall of 1952 the outlook is excellent. Looking back over our "howgozit" charts of the past few years, we see that we have passed successfully through several rather turbulent "fronts" that developed in the post war "low" and are now climbing into clearer air with a good prospect of CAVU conditions ahead. Your Institute is ending the first twenty years of its flight with everything turning smoothly and with a good supply of fuel in its tanks. S. P. J.

Fourth International Aeronautical Conference

It will be recalled that I.A.S. President Wellwood Beall announced at the Annual Summer Meeting Dinner on July 16 that the Fourth International Aeronautical Conference with The Royal Aeronautical Society was tentatively scheduled for mid-September, 1953, in Los Angeles. This date had been selected by The Royal Aeronautical Society as the earliest practicable one for 1953.

Immediately following the announcement it became obvious that the close proximity of the date to the regular Aeronautics Meeting of the S.A.E. would create an undesirable situation with respect to both meetings. After consultation with the Management of the S.A.E., it was agreed that any such conflict should be avoided, and we advised the R.Ae.S. that a meeting at that time in the United States could not be arranged. Several alternatives were proposed, including: (A) combining the Fourth International Aeronautical Conference with the Twenty-Second Annual Meeting of the I.A.S. in January, 1954; (B) postponing the Conference until the Spring of 1954; or (C) holding the Conference again in England in September, 1953, in conjunction with the annual S.B.A.C. Show.

At a meeting of the Council of the R.Ae.S. on September 25, these matters were considered and suggestion "C" was adopted. An official invitation was cabled to the I.A.S., and at a meeting of the Executive Committee of the I.A.S. Council on October 30 the invitation was unanimously accepted.

Exact details of the dates and locale are not yet agreed upon, but the probabilities are that our joint technical sessions will be held in London during the last week of August. Program planning is now under way, and sometime during the early Spring advance arrangements will be made for transportation, housing in London, plant visits, etc.

I.A.S. members will be kept advised of these plans through the *Review* so that all who wish to attend the Conference can make arrangements to do so well in advance of the event.

Those of our members who attended the 1947 Conference in London and the 1951 Conference in Brighton know how important and worth while these conferences are both from the technical standpoint and from the standpoint of relations with our colleagues overseas.

We anticipate a large and representative I.A.S. delegation for the Fourth International Aeronautical Conference in 1953.

Pilotless Aircraft

The Establishment of Structural Design Criteria

ROBERT GOLDIN*
Bell Aircraft Corporation

ABSTRACT

The general approach and various specific methods for establishing design criteria for development of guided-missile structures are presented. Necessary criteria are classed into five categories: (1) flight and ground loads; (2) rigidity criteria; (3) factors of safety and allowables; (4) stress analysis; and (5) structural tests. Aircraft design criteria presently in use are briefly reviewed to provide a basis for solution of the guided-missile criteria problem. Each of the five groups of design assumptions is examined, and ways of obtaining usable answers are suggested. The necessity for a planned approach to the various aspects of the structural design problem is stressed.

(I) INTRODUCTION

THE APPROACH TO THE STRUCTURAL PROBLEMS of pilotless aircraft during their early years of development was strictly patterned after already existing methods used in piloted-aircraft design. This approach continued without change or attempt at improvement until recently, and even now there is room for better coordination of engineering efforts. This article summarizes the basic elements of the structural design problem but makes no attempt to present complex methods of solution for details of the problem.

The early application of the conventional-aircraft designer's approach to the structural problem is not in itself incorrect. The basic elements present in the structural design of conventional aircraft are also present in pilotless-aircraft design. Briefly summarized, the common elements of the problems confronted in any aircraft structural design can be stated by the following questions:

(1) What flight and ground load criteria shall be applied?

(2) What rigidity criteria govern the structural design?

(3) What factors of safety shall be applied, and what stress allowables are to be used?

(4) What structural analyses shall be prepared, and at what stage of development shall they be finalized and submitted?

(5) What structural tests shall be made, and at what stage of development shall they be accomplished?

The civil and military branches of the Government and the aircraft industry had developed more or less uniform design load criteria providing the answer to question (1), since the physical well-being of the pilot was the primary governing factor in their calculations. Until relatively few years ago, question (2) was a somewhat minor consideration and, as such, was usually investigated *after* a structure was designed rather than being utilized to *create* a design. By common usage and long precedent, more or less uniform factors of safety and stress allowables were achieved. The significance of the decisions and customs established was, however, appreciated by only a handful of engineers. As for questions (4) and (5), analyses and tests to be performed were established more or less routinely by the obvious necessity of safeguarding the pilot and crew to the greatest practicable extent. Hence, at the time of the advent of pilotless aircraft such as we know them today, a large mass of accepted criteria, custom, and standard practice relative to aircraft structural design had been absorbed by the engineer. If necessary, it was not difficult for him to find criteria for the design of any piloted-aircraft component somewhere in accepted standard specifications. It was soon discovered, however, that many of these criteria were either too conservative or too unconservative for realistic engineering of guided-missile designs. No longer was safety of a pilot the key problem; furthermore, the pilot's physical limitations, which had provided well-understood upper limits to maneuvering severity, no longer guided the designer.

The earliest efforts to fill the criteria void that existed for these new types of aircraft involved attempts to write general design specifications for missiles to replace the ones with which engineers had been so contented for application to conventional aircraft. These, however, have never fully succeeded in accomplishing their purpose for two reasons: (a) The variety of types of missiles (see Fig. 1) simply does not lend itself to detail criteria specification such as was developed for conventional aircraft. (b) It was not feasible to invent acceptable detail design criteria until sufficient design experiences had been accumulated to provide proof of adequacy and precedent for its use.

It is worth while to note that a significant portion of conventional-aircraft criteria was evolved from experience that indicated existence of chronic troubles in some components under certain operating conditions.

Probably one of the most useful of all these efforts on behalf of the structural engineer was the brief specification requirement for missiles, by one of the services, that the contractor determine for himself what the answers to questions (1) and (2), stated earlier, are for

* Head, Criteria and Loads Section, Structures Department.

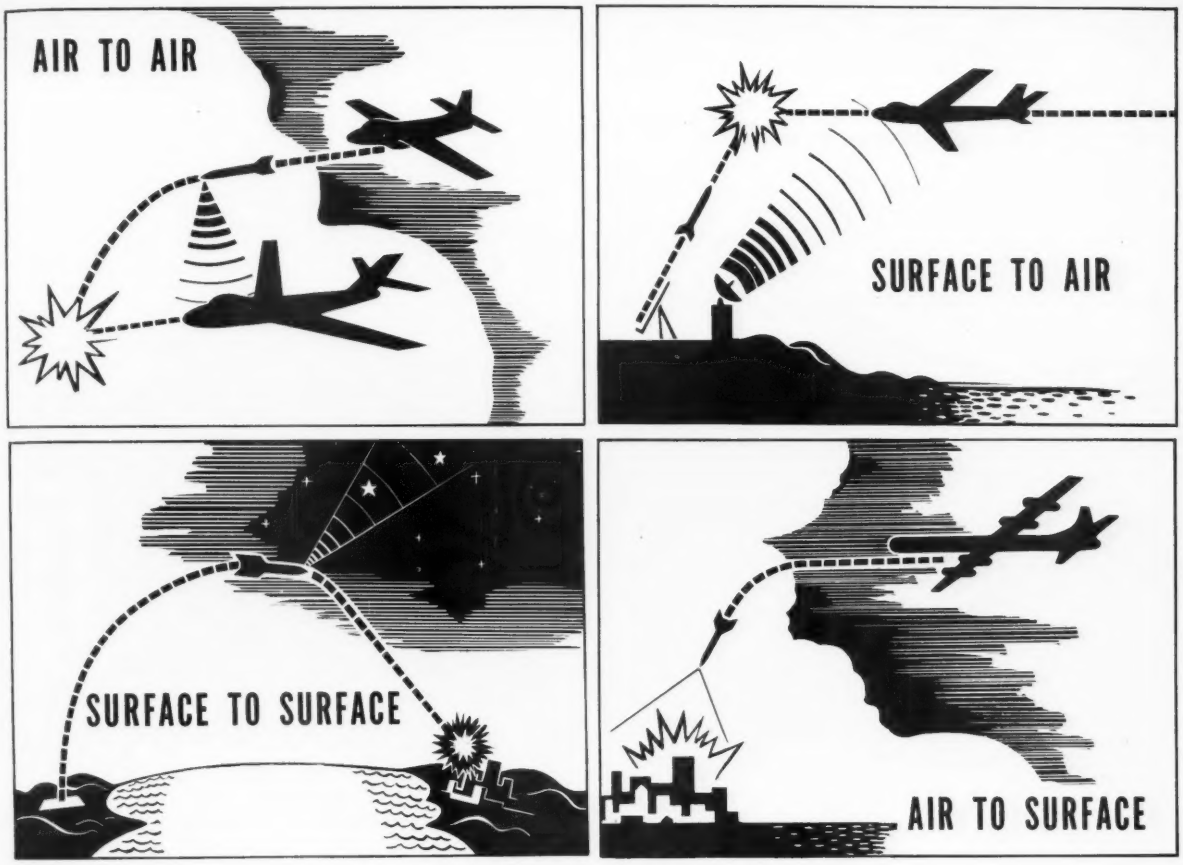


FIG. 1. Some types of guided missiles.

his missile. That agency at the same time arbitrarily gave usable answers to questions (3), (4), and (5), which for all intents and purposes are procuring agency policy questions anyway. It is believed that the key to the structural designer's problems is aptly and bluntly provided in the aforementioned requirement—namely: *In pilotless aircraft design, the structural engineer cannot turn to standard and established specifications for his design criteria; he must invent, or derive, criteria to fit his particular configuration* (see Fig. 2). Once the engineer accepts this thesis, he shortly discovers that this involves establishing, by use of his common sense, experience, and analytical thinking, the answers to the five questions outlined above and, further, that this task only *seems* difficult because formerly it had been done for him through a long gradual evolutionary process.

In the sections that follow, a rational grouping of the items that make up structural design criteria is provided. When approached in this manner, the writer has found that the establishment of sound basic criteria for the structural design of a number of widely differing missiles was not at all difficult. As a matter of fact, the "exercise" involved in reviewing the source of basic assumptions each time was found to lead to clearer appreciation of the overall engineering order of significance. As a result, so-called "*accurate*" *loads calculations involving many man-months were, in some cases, quickly and confidently replaced with conservative simple-assumption-type loads determinations in recognition of the fact that the basic assumptions were in themselves arbitrary to the extent of ±25 per cent.* With experience, "order-of-accuracy" becomes a well-understood and well-appreciated guide to consistent design, and the predisposition to serious omission or numerical error becomes less likely. Even today, the procuring agencies are only partially able to specify detailed, definitive structural design criteria for pilotless aircraft. It is therefore mandatory that the engineer fill in and expand the limited general specification requirements with his own assumptions of recommended design. To accomplish this, it actually has been found most convenient to express such basic data as specification requirements, promulgated in contractor-prepared specifications designed to supplement the Government-contract requirements. By using this tool, the administrative engineer can pass on to his supervisors, in the various sections of the department, a somewhat formal-looking document. For the pilotless-aircraft structural engineers, this provides the basic criteria previously summarized for them in the time-honored Air Force Spec. 1803 and BuAer Spec. SS-1.

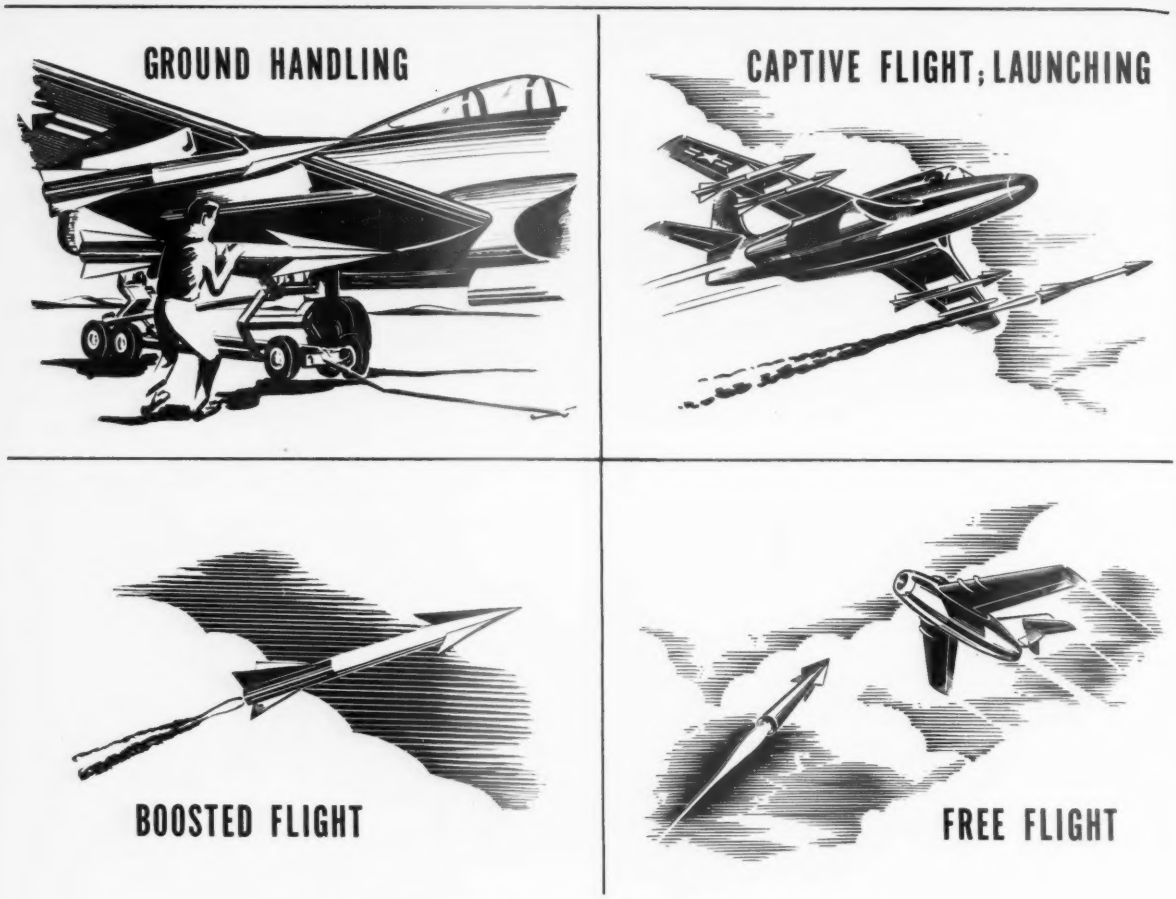


FIG. 2. Typical operating conditions of an air-to-air guided missile.

(II) DESIGN LOAD CRITERIA

The first criteria necessary before the structural engineer can begin any kind of loads analysis is a set of basic design weight assumptions. Sometimes a preliminary design estimated value is used for a time, and then, only because it had been used in earlier analysis, it is picked up and re-used in the permanent analysis. This analysis becomes the final check of structural adequacy and the source for test conditions and information for use in salvage dispositions and is embodied in reports submitted (if required) to the procuring agency. Such anomalies occur as the carrying of a design weight of 12,152.8 lbs. into calculations not only performed with a 10-in. slide rule but also involving a load factor value (which was chosen almost arbitrarily) having only one significant figure. It is here that the concept of design-for-bracketed extremes is first fully appreciated. An estimated weight figure must be scrutinized with great care to determine (a) how much it can be expected to change, (b) how directly it affects the structural design, and (c) what number—rounded off to no more than three significant figures—will adequately represent the desired design objective and provide a realistic base for all structural calculations. It must be remembered that stress calculations, static tests, and flight operational restriction criteria are all interrelated and often require many months or even years to complete. If the design weight is permitted to change, even in the fourth or fifth significant figure in the case of irrationally and accidentally selected design values, a state of chaos necessarily results within the stress analysis, which is like the proverbial "changing horses in the middle of a stream." The foregoing applies with the same force to selection of centers of gravity for use in design, and the following must be examined: What shifts must be expected, and for what magnitudes of shift (for various pay loads) must provision be made? Accordingly, it has become the practice at the Bell Aircraft Corporation to accomplish the following prior to the start of any detail structural analysis:

(1) For each of the major critical design conditions, a set of design weight values is selected and specified as a permanent part of the model specification requirements.

(2) A set of design c.g. locations is selected and established for each weight condition.

(3) A weight and balance report is prepared and made part of the formal analysis, providing specific dead-weight distributions for each of the design c.g.

limits and each of the design gross weights. To accomplish the foregoing, ballast may be arbitrarily added to the best-estimated weight to result in *design* weight; and ballast, pay load, and/or test equipment logically is moved around to result in *design c.g.* limit values.

(4) None of the foregoing is permitted to change throughout the development program unless a drastic redesign occurs, which then requires the approval of the Chief Structures Engineer after the Project Staff is made aware of the engineering costs involved in making the change.

Ground loading criteria can be established as a not too difficult second step in establishing basic assumptions. Too often, these items are neglected as trivial nonproblematical elements of the structural analysis which can be handled at later stages. Although in many cases this is true, it is a fact that with the investment of only a little time for basic criteria evaluation much embarrassment and/or subsequent loss in design time can be avoided. Criteria for hoisting and loading, for jacking, for movement in a dolly, and for other similar conditions are available in specifications such as ANC-2 and others for ordnance handling equipment. Even the perennial rail-shipment condition was faced at the Bell Aircraft Corporation by providing strength in all parts of the missile (at little cost in weight) for a definite fairly high value of acceleration. This value was not nearly equal to the high shock load values expected but permitted the shipping-container designer to have a definite available-strength limit to the shocks which he could allow to be experienced by the missile.

Another set of loading conditions must be established for conditions experienced by the pilotless aircraft prior to, or during, launching. In the case of air-launched missiles, the problem is merely that of determining the three or four critical design loading combinations that can be imposed by the carrier aircraft because of its ground and flight conditions. If the missile is enclosed in the bomb bay, these loads are all represented as accelerations acting on the missile's design weight at its extreme design c.g.'s. For those missiles that are exposed to the air stream, air-load and acceleration-load combinations must be evaluated. Relatively simple computation and application of common sense can often resolve the number of critical conditions for detail load calculation down to only a few, and, if these are then described and specified as a *requirement*, the lost motion and floundering about in detail critical-loadings analysis are reduced to a minimum.

In the writer's opinion, the difficulty of establishing structural design criteria for pilotless-aircraft flight conditions has been somewhat exaggerated. Evaluation of required maneuverability, which certainly drastically affects the structural design, is basically an aerodynamic problem. Flight trajectories must be studied, and hit probabilities using various degrees of maneuverability must be estimated or calculated. The end results, selected on the basis of least overall cost or simply aerodynamic limitations, are merely design values of acceleration and speed. Once these have been selected, with sufficient data available to determine what physical characteristics actually *limit* the values, the structural engineer can proceed. In some pilotless aircraft, for example, the aerodynamic configuration is unstable, and dependence upon not exceeding a given value of acceleration must be placed on a *g*-limiting device. This case is not dissimilar to that of the piloted aircraft, where the pilot, who observes a restriction, effectively is the *g*-limiter. The problem then becomes one of establishing (a) gust loads, possibly using gust-probability-of-occurrence data to justify use of less than the accepted standard 50 ft. per sec. gust; (b) combinations of steady maximum-acceleration maneuvering condition loads, using the controlled *g*-limited values of acceleration; and (c) various logically selected dynamic-condition loads, providing critical load distributions for control surfaces and also angular acceleration increments to dead-weight loads for design of installations not in the vicinity of the total aircraft c.g. The pilotless-aircraft structural criteria engineer must bear in mind that probabilities enter into the picture as in conventional aircraft; there, it must be remembered, gust loads are *not* combined with maneuver loads and rolling maneuvers are *not* combined with maximum maneuvering acceleration conditions. Accordingly, he must logically chose (a) maximum severity conditions singularly applied, or in combination if they are designed to occur combined; and (b) moderate severity combinations of conditions, or singularly applied overly severe conditions that individually supply built-in conservatism to take care of probable combinations. These must satisfy the reliability requirements that usually are as high for structures as those required in piloted-aircraft design. Usual engineering accuracy in selection of probability of combination is exceedingly difficult (and often impossible) to attain. It is therefore logical to *estimate* the order of conservatism needed and apply it to loads determinations for singularly applied and "easy-to-design-to" conditions. It is pointed out, however, that in missile design the combination of gust with a percentage of maneuver loading *is* logical on a probability basis, for there is no pilot on board to slow down speed and reduce severity of maneuvers when the air is rough. It is also convenient to bear in mind that, where a design is such that *maximum conceivable* loads can be applied without compromise to any part of the system, such a load simply derived becomes a safe and logical design value. It is conceivable, for example, that a small, dense, air-launched missile, subject to drastic angle of attack changes, might have its lift and control surfaces stress-analyzed for full dynamic pressure loading. This analysis is immediately calculable and completely conservative.

Other types of pilotless aircraft demand different ways of expressing the basic criteria but still have such derived in a manner similar to that described above. For example, a missile that is aerodynamically stable and has either no controls or preset controls might be flight-condition-analyzed in the following manner: (a) Establish angle of attack due to misalignment of sur-

faces (or preset surfaces) and of line of action of thrust; (b) establish a reasonable value of gust velocity, and determine its effective angle of attack; and (c) multiply (b) by an "overshoot" factor that logically could not exceed 1.5 to 2.0, and, then, add that to (a) and calculate loads. Special features will also necessitate special criteria, such as the transient starting thrust of some rocket engines may exceed the nominal value by 50 per cent, and the normal transient variation might be ±10 per cent. Usually in pilotless-aircraft design the high dynamic pressure conditions (low-altitude) result in highest loads; however, lower load conditions may prove to be more critical for structural design at higher Mach Number where aerodynamic heating effects become predominant. In all of the special cases, as well as in the more common cases, the criteria approach that leans heavily on "what is the *maximum conceivable* severity?" is not only the simplest but often the most logical. Frequently, at Bell Aircraft a loading condition will be given out for use with the following caution: "If the load is difficult to design for, results in more weight than has been planned, or otherwise seems unreasonable in the particular design, request that it be re-evaluated—because it is a *conservative* load."

(III) Rigidity Criteria

The importance of rigidity criteria in design of all aircraft has been increasing rapidly in the past decade. The terms flutter, divergence, control reversal, and aeroelastics are relatively new, and it has been only recently that the average structural engineer has begun to have a slight familiarity with their meaning to him as a stress analyst. With the increasing quantity of transonic and supersonic design projects, the importance of this design aspect has caused a significant number of engineers to become "strain-analysis" advocates. Pilotless-aircraft designs have lent considerable emphasis to this point of view, for increasing percentages of total structural weights are now governed by rigidity requirements. In one missile project the writer has seen the following occur:

(a) The aircraft body design was governed entirely by the necessity of providing stiffness to keep the angle of deflection between canard stabilizer and wing surfaces from reducing static stability to the point of instability as maneuvering load is developed.

(b) The wing thickness and, hence, wing weight, since these were solid, could not be reduced to the point that bending stresses would be critical because aileron reversal occurred first. In this particular design, considerably more than half the structural weight was governed by rigidity criteria, and, therefore, many of the large stress margins of safety were misleading and had no practical significance. Therefore, it actually is becoming necessary for the stress analyst to consider the feasibility of showing a "margin of safety for rigidity." Furthermore, although in the past it was almost always reasonable virtually to ignore rigidity criteria while a design was selected, it is now necessary that structural sections be selected by trial and error to satisfy rigidity demands rather than stress limitations.

This trend has resulted in a definite necessity for establishing rigidity criteria at the same time that the basic loads criteria are selected. The following rigidity problems must be considered and appropriately covered:

(a) How much margin must be provided between highest speeds expected in service and flutter and divergence speeds?

(b) How much loss in static stability can be tolerated due to body deflection?

(c) How much loss in control effectiveness will be permitted due to torsional deflection of the fixed surface?

(d) How much deflection or wind-up will be tolerated in control systems?

(e) How much torsional twist will be permitted in a missile body between the wing and the station where the roll stabilization gyro is located?

(f) What angular displacements can be tolerated between the missile axis and the carrier-aircraft axis without affecting the accuracy of the guidance system?

(g) What natural frequencies can be tolerated in the major elements of the air frame in view of the vibration environments that exist?

Experience at Bell Aircraft has taught us that, before a design is completed, each of the foregoing must be answered or proved not critical (the earlier the better), even if arbitrary assumptions must be resorted to in order to obtain a base for subsequent analysis.

As the importance of rigidity limitations increases, the necessity for the structural engineer to express "margin of safety" in a number that has significance also increases. It is believed that to the structural engineer such a number should be as nearly as possible a direct function of weight. Unfortunately, the relation between deflection and weight is not usually so constant as is the relation between stress and weight. In a number of cases, the writer has observed that the use of an expression for margin of safety similar to the following is useful: For body deflection,

$$\text{M. S.} = (\text{actual shell thickness} \div \text{required shell thickness}) - 1$$

It is apparent, however, that firmly established methods for dealing with such problems as the above cannot be specified with assurance until more experience has been accumulated. The establishment of basic *rigidity criteria*, however, can and must deliberately be accomplished in order to assure consistency in the structural design of pilotless aircraft.

(IV) Factors of Safety—Allowable Stresses

Sound structural design practice demands recognition of risks in design, reliability of structural components relative to overall system reliability, as well as assurance of safety of personnel for pilotless-aircraft design conditions experienced near the human operators

or handling crews. In the case of the latter, there is the set of precedents that govern piloted-aircraft design, and, accordingly, the time-tested ultimate factor of safety of 1.50 can be applied. Relative to the "remote-from-personnel" conditions, however, new customs must be established. Here, the engineer is torn between the knowledge that stress analyses (at best) have an accuracy of ±10 per cent and that systems reliability is an extremely important item, while, at the same time, weight must be kept as low as possible. The best answer is not easily established, and much strong opinion is continually expressed on this subject. One rather reasonable approach is to specify that the design be made (neither conservatively nor unconservatively) to determine limit stresses and that a yield factor of safety of 1.15 be used to provide an arbitrary ignorance factor between the service-experienced condition for which reliable strength is mandatory and the actual design condition.

Safety factors must be selected not only for the basic aircraft structure but also for various components. The amount of "ignorance" which exists relative to different components varies considerably. Hence, while overall structural design may be adequately covered by a yield factor of safety of 1.0 or 1.15, it ordinarily should be higher, say 1.33, for such items as pressurized tanks. Such parts as hydraulic tubing and fittings, where intricate detail stress analysis is difficult, unwarranted, and confused by fatigue considerations, require a yield and/or proof-test factor of 2.0. Safety factor criteria may also be required for control systems and for bearings, where higher degrees of reliability may be in order.

The problem of selection of stress allowables is experienced every day in conventional- as well as pilotless-aircraft design. Such documents as ANC-5, BuAer's SB-73, and research reports on the subject are standard aids to the engineer. The steel and aluminum industries continually contribute to expanding the knowledge in this field, and considerable work is being done in establishing allowables under various temperatures and fatigue-cycling conditions. Clear-cut definition of use of minimum dimensions and minimum gages and use of "90 per cent probability data," is part of the structural criteria problem. When the foregoing is not defined by the procuring agency, at Bell Aircraft some attempt is made to stabilize these basic assumptions either as part of the criteria established in the contractor's proposed model specification or as part of data used by the stress analysts as guides in their detail analysis.

(V) Structural Analysis Reports

Regardless of whether or not the structural engineer likes it, it remains true that sets of engineering reports are his only tangible product. In these reports are contained the results of weight estimates or calculations, design criteria and basic structural loads, the detail stress analysis, strength summaries and operating restrictions,

Fig. 3. Vibration tower designed by Bell Aircraft Corp.

static and dynamic tests, and structural flight tests. When presented in an organized and consistent manner, a set of such reports contains a wealth of information regarding structural capabilities for salvage and future redesign purposes. Furthermore, in the writing of such reports, the engineers themselves are almost inadvertently forced to examine practically every significant condition, or component, which might cause difficulty. After a few experiences with designs where analysis was not formally assembled—since it was not required—it has always been found to be worth while to assemble formal reports, even if they are not submitted to the procuring agency. It should be remembered that the detail or length of a structural analysis of any part of an aircraft is governed primarily by the time available, and a wing analysis can be accomplished in a few man-weeks or a few man-years. But in either case, if the assumptions are not permanently recorded and presented in a logical sequence, the material is of little use after the initial design is established.

At the time that the structural design program is established, it becomes part of the overall "criteria" problem to establish the detail or scope of the analyses to be accomplished and formalized. This may in part be specified by the procuring agency. On the other hand, even when it is so established, definition of the time for, and relative importance of, the individual analyses to be performed is necessary. When this is done, it is usually found that consistency can be attained with elimination of such occurrences as 100 pages of analysis for one frame as compared with 50 pages for the entire horizontal tail. It is also conven-

FIG. 4. High acceleration centrifuge with the author at the controls.

ient to imply the intricacy of the analyses either by indicating a breakdown of reports to be prepared or by showing submittal (or completion) dates that are appropriately restrictive.

(VI) Structural Tests

Structural tests are performed usually for any of three basic reasons: (a) to establish allowable loads or stresses for particular materials, joints, or conditions for which insufficient data are available; (b) to verify the stress and rigidity analyses by actually applying the design ultimate and/or yield loads; and (c) to verify design loads and load distributions during actual operating conditions. With the foregoing in mind, the job of establishing the scope of each of the groups of tests and setting up the *actual* tests is not too difficult. Again the primary problem is consistency. For example, there is no point in performing a static test for a design in which an arbitrary ignorance factor of 3.0 is used and the stress analysis is considered reliable within ±20 per cent. On the other hand, if the loads are considered to be +10 and −0 per cent of actual expected loads and the stress analysis is accurate to within ±20 per cent, then a static test is definitely warranted, but flight-test work is not needed. Fig. 3 shows an example of an operational and structural test especially developed for the qualification of certain guided-missile components.

For many small components used in a missile, structural tests may be combined with operational tests of the unit. This is especially true where large accelerations (say above 10*g*) are involved. Prior to the advent of pilotless aircraft, structural design of mounts for such things as radio equipment, small tanks, and compasses would be governed primarily by common-sense considerations of limiting deflections of such mounts under nominal loads. Now, however, it is necessary to have a vacuum tube, as well as its structural mounts, capable of withstanding such combinations as 20*g* due to thrust and 15*g* due to vertical maneuvering, *while operating*. Both conditions can be checked simultaneously by operating the tube while it is experiencing design accelerations on a centrifuge (see Fig. 4).

(VII) Conclusions

Briefly summarized, the structural criteria engineer must define the structural design problem by establishing loads and rigidity criteria, safety factors and sources of material allowables, and the scope of structural analyses and tests to be completed. While the foregoing is accomplished, consistency must be maintained with respect to the concentration on each of the separate parts of the problem. The most convenient place to accomplish this is in the model specification and associated procurement-contract documents. In the case of conventional aircraft, most of this organizational work is already accomplished in well-accepted standard specifications. Because of the newness and variety of pilotless aircraft, however, a considerable amount of this type of thinking must be done by the air-frame contractor and redone for each new design. Where the missile model specification is prepared by the contractor and submitted to the procuring agency for approval, it is found that *that* basic specification becomes a convenient place to summarize all of the pertinent criteria considerations discussed.

For emphasis, it is worthy again to note that *all* of the problems are already familiar to the aircraft designer. Only the questions of magnitude and relative importance of the separate considerations are different for the various types of guided missiles. The approach presented herein involves reflecting back to the *sources* of the familiar criteria long used in conventional aircraft design. The advantage of so doing is useful not only for application to varieties of missiles but also for preparing the criteria engineer for the day when he is asked to establish design assumptions for an inhabited space vehicle. Since *any* structural design involves considerations of the kind outlined above, the basic approach to the problem of structural analysis of a space ship is also covered. With thinking organized in this manner, a highly rational approach to any such new problem is easily obtained.

The Effect of Propeller-Control Parameters on Gas-Turbine Power Ratings and Flight Efficiency

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Introduction

It has long been recognized that the turbopropeller installation requires a close correlation between propeller and engine throughout all stages of their development. This is true in the aerodynamic design of the propeller where the selection of the proper reduction gear ratio is vital to the realization of maximum performance. It is true in the control design where the propeller and engine schedules are intimately related and the control sensitivities and failure protective devices are so interdependent. It is true in the structural design where loads and vibratory excitations may interact between propeller and engine.

One additional phase wherein the interrelationship is perhaps less immediately apparent comprises the subject for this paper. This is the effect of the propeller control on the engine-power ratings and efficiency.

The selection of the schedule for full and part throttle operation, the type of fuel control and engine protection, and the availability of engine power during transients are all dependent on the propeller-control parameters.

To break the subject down for the moment to its simplest fundamentals, we may question why we have a propeller control at all. Basically, the purpose of the control is to release from the engine the power available at any given throttle setting over an extreme range of operating conditions. The simple fixed-pitch propeller would be equal to a constant-speed propeller at its design condition but would restrict the performance at any other condition. This is because the rotational speed would be limited by the fixed blade angle at any velocity below the design condition, and the power would have to be limited above the design velocity to prevent overspeeding. Fig. 1 demonstrates this point. Superimposed on a plot of thrust/pounds fuel/hour velocity in miles per hour for a typical propeller and a typical jet is a curve for a fixed-pitch propeller designed for an air speed of 400 m.p.h.

The use of such a propeller on a conventional turbine engine would be prohibitive because of the inability of the engine to accept the underspeeds inherent in such an installation at less than design velocity. For a free-turbine type of engine, however, where the propeller-driving turbine can sustain a large variation in speed without appreciable loss in power, such a configuration is not outside the realm of possibility. The drop in r.p.m. between the design point and the static condition at takeoff power is less than 20 per cent for the fixed-pitch propeller on which Fig. 1 is based. It was assumed that negligible change in shaft horsepower occurred over this r.p.m. range.

The control and stability of this system would, of course, have to be accomplished in the engine control system; the penalties of such a control will be discussed later in this paper.

The important point to be noted from Fig. 1 is that the difference in performance between the two propeller curves is obtained at the price of propeller controls. A major portion of the difference is obtained by the use of the constant-speed propeller, at an increase in propeller weight over fixed pitch of approximately 25 per cent but with a gain of certain other advantages such as feathering, reverse thrust, etc.

The balance of the performance difference is obtained by refinements in the control system. Unfortunately, the price of refinements is often complexity, with a resultant loss in dependability and ease of maintenance.

Typical Turbine Characteristics

In order to examine more closely the effect of some of these control-system refinements, a typical turbine

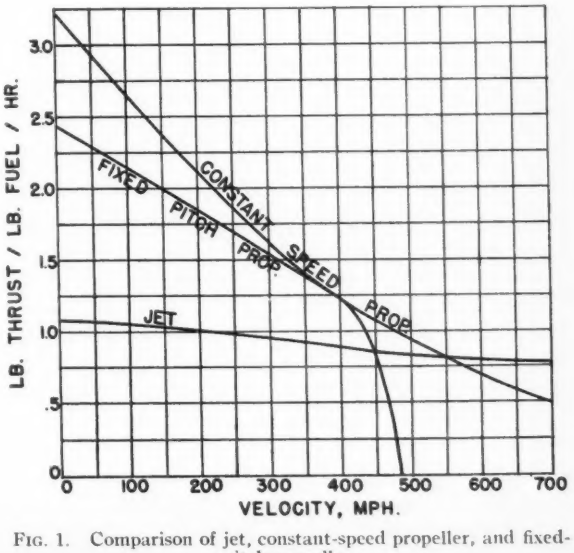

Fig. 1. Comparison of jet, constant-speed propeller, and fixed-pitch propeller.

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† Supervisor of Technical Analysis.

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engine was evolved. The turbine-engine plots showing horsepower versus rotational speed for fixed values of fuel flow and turbine inlet temperature are presented in Figs. 2 and 3. These curves represent low and high velocity, respectively. They are based on an average of several engines of two different manufacturers to ensure representative relationships among the variables. The engine is a simple, axial-flow compressor, single-power-section type.

The obvious trends shown by the curves are the increase in shaft horsepower on constant temperature lines and the flatness of, or decrease in power on, constant fuel lines within several per cent of rated r.p.m. It will also be noted that the surge line is approximately parallel to the temperature lines at some value of overtemperature.

These trends lead to one rather obvious conclusion. For inherent temperature and surge protection and for certain performance gains that will be pointed out later, the fuel control should vary fuel to maintain a constant temperature with variations in engine speed. This is not a new conclusion, but it is felt that the full benefits of constant-temperature operation have not as yet been adequately realized or exploited.

The difficult problem of protecting against compressor surge is minimized with the temperature control, since the general trend of the temperature controller is to carry an underspeeding engine parallel to the surge region rather than perpendicularly into it. The temperature controller also provides temperature protection at the smallest perceptible temperature error, while the overtemperature protection on any other system must have a considerable deadband to prevent interaction between it and the primary fuel control.

The substitution of one primary temperature control to replace an overtemperature topping control, a surge protective device, and a primary fuel control of the droop or ambient sensing type should show definite savings in components and improvement in dependability.

The temperature control may be either a speed and ambient sensitive scheduling device or a direct sensing device. With present thermocouples having time constants shorter than the heat build-up time in the critical turbine parts, the direct sensing device appears quite feasible.

Speed Transients

Determining the relationship between the engine and the propeller control requires that we depart for a moment from the engine characteristics and examine the source of the speed transients that dictate the controls. Speed transients in an engine-propeller combination result from changes in load due to aerodynamic transients and to throttle transients. The aerodynamic transients may in turn be due to such short-time effects as rough air or to the more sustained effects of airplane accelerations or decelerations during take-off, climbs, etc.

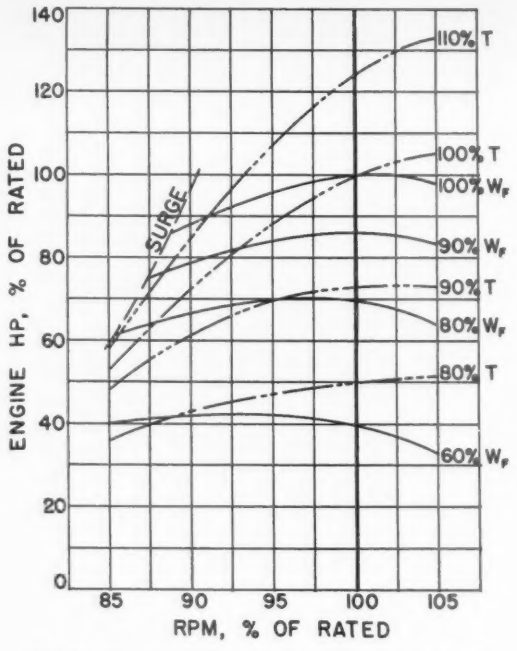

Fig. 2. Representative engine, 100 m.p.h., sea level.

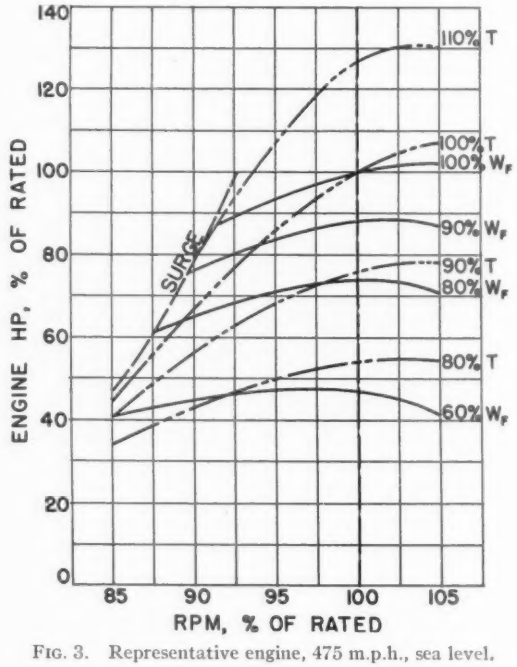

Fig. 3. Representative engine, 475 m.p.h., sea level.

The throttle transients can, of course, occur under any operating condition. The most critical, however, from the standpoint of propeller-pitch-change rate required while in governing is the rejected landing or wave-off condition. Here, the rapid application of full power at a low flight speed represents the largest change in blade angle ever desired, and in the shortest time.

It might be noted at this time that the maximum sustained aerodynamic transient ever actually applied to an airplane represents a rate of change of load on the

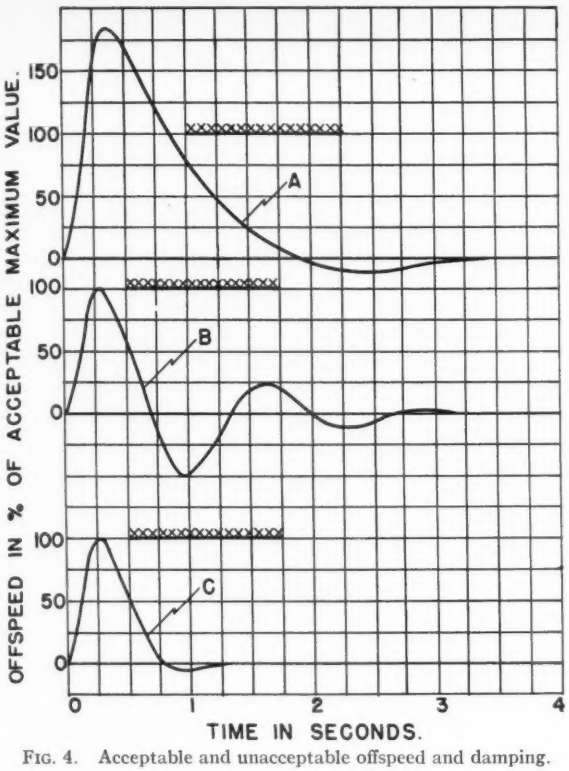

FIG. 4. Acceptable and unacceptable offspeed and damping.

propeller equal to only about 10 per cent of that resulting from the maximum throttle transient at minimum flight speed. This fact will be amplified later in the paper.

PROPELLER CONTROL FUNCTION

It is the function of the propeller in the case of the normal propeller speed governing system to restore the offspeeding system to equilibrium at the desired rotational speed within acceptable offspeed values and with an acceptable degree of stability or damping. Fig. 4 shows a plot of three speed responses for a typical turboprop installation. Curve *A* has a value of error sensitivity, called K_1, required to give the desired system damping but which permits offspeed in excess of the maximum desirable limits based on experience with numerous turboprop installations. Curve *B* has a K_1 increased to give acceptable offspeed but is considered unacceptable from a damping standpoint. The obvious solution is the use of additional control damping to provide a damped response with the high K_1 value. This is shown in curve *C*.

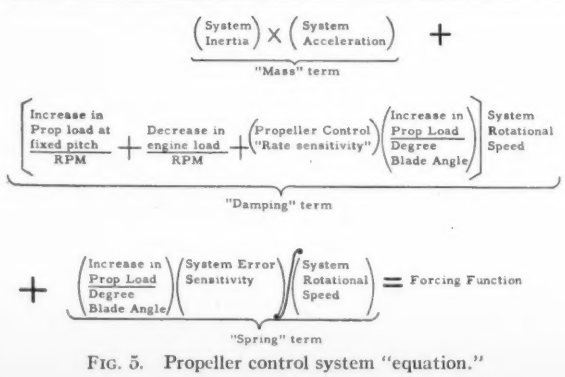
(System Inertia) × (System Acceleration) +
"Mass" term
[Increase in Prop load at fixed pitch / RPM + Decrease in engine load / RPM + (Propeller Control "Rate sensitivity") (Increase in Prop Load / Degree Blade Angle)] System Rotational Speed
"Damping" term
+ (Increase in Prop Load / Degree Blade Angle) (System Error Sensitivity) ∫ (System Rotational Speed) = Forcing Function
"Spring" term

FIG. 5. Propeller control system "equation."

Additional control damping can be accomplished in three major ways. The "equation" of the engine-propeller system, shown in Fig. 5, illustrates two of them.

It will be noted in the "damping" term of the equation that either propeller control rate sensitivity, called K_2, or change in engine load with r.p.m. may be used to increase the damping. The latter would be accomplished by fuel droop—i. e., reduction of fuel with overspeed and increase with underspeed. The third method is by the use of a torque control on the propeller and speed control on the fuel flow which gives a relatively stable system. It might be pointed out that a fourth, if somewhat impractical, method presents itself in the equation in Fig. 5. Increasing the rate of change of propeller load with r.p.m. will also increase the damping, but this requires changes in propeller power absorbing ability which are impractical from an aerodynamic and structural standpoint.

EFFECT ON POWER OUTPUT

Let us examine the effects of each of these methods on the power ratings and power availability of the installation. The use of fuel droop, while identical with the use of rate sensitivity from a control standpoint, is much less desirable from an operational standpoint.

During take-off, for example, the propeller must be operating at an overspeed in order to provide the pitch-change rate required to accommodate the aircraft acceleration. With a constant-temperature system, the engine actually shows a slight increase in power during the take-off overspeed. With the drooped fuel system, there is a loss in the power and thrust available for take-off.

This effect is illustrated in Fig. 6, which is an expansion of the rated power area of Fig. 2. A drooped fuel line is shown which gives the system the same stability as is obtained with an optimum system having K_2. The overspeed occurring during a normal take-off is the same in either case and is shown on the figure. The loss in take-off power and, hence, thrust is approximately 4 per cent. When this value is considered in terms of the weight of power plant that it represents, the loss is of the order of 200 lbs.

A reduction in power during take-off also occurs on the torque-control type of system. In order to increase propeller pitch at a rate commensurate with the aircraft acceleration, the torque-controlling propeller must be sensing an under-torque condition. The speed-sensitive fuel system will maintain rotational speed by supplying the fuel required at the under-torque load. Therefore, the system will be operating at a reduced power and thrust. The system having propeller control rate sensitivity is the only one that permits full

power or even a slight increase in power during the quasi-steady-state take-off condition.

Another undesirable aspect of the drooped fuel system is the fact that during an underspeed the increase in fuel flow obtained results in an increase in the operating temperature. Fast overtemperature protection on this type of control will result in an oscillatory system. Even though this temperature increase occurs only during transients and quasi-steady-state conditions, its cumulative effect on engine life should be considered. Referring again to Fig. 6, it will be noted that in order to prevent overtemperature during a normal speed oscillation at take-off power, for example, it is necessary to derate the engine approximately 2 1/2 per cent.

Present information on the effects of short-term overtemperatures is not adequate or conclusive enough to determine whether this amount of derating is mandatory; however, it is inherently true that repeated overtemperatures will reduce the overall life of the engine components. The engine will in the course of passing its required qualification and endurance testing indicate its inability to withstand these overtemperatures. With the K_2 system having temperature control on the engine, the underspeed occurs on a line approximating fixed temperature, depending on the relative speed of the transient and the temperature controller.

If the engine is derated for steady-state operation to prevent these overtemperatures, then the cumulative effect of this derating plus the loss of power during take-off is of the order of 6 per cent. This represents a power-plant weight of approximately 300 lbs. which is not being exploited on take-off.

One other observation regarding the relationship between engine performance and propeller-control parameters can be made by referring back to Figs. 2 and 3. It will be noted from these figures that the peaks of the fixed fuel lines, representing the best specific fuel consumption at any given horsepower level, fall on a speed schedule that closely approximates fixed-speed operation. The only condition at which any perceptible penalty of fixed-speed operation is noted is on the low velocity curve where the loss in specific is approximately 1 1/2 per cent at 40 per cent power. This loss will be less at actual cruise velocities, representing the only type of operation where such a low power would be scheduled for any appreciable length of time.

Operation on a scheduled speed requires resetting of governing speeds and employment of various devices to eliminate the reverse thrust effect of instantaneous governor resets. The decision to operate on a fixed-speed or varying-speed schedule is, of course, dependent on the detail requirements of any given installation, but it is pertinent to note that much of the so-called complexity of propeller controls can be avoided early in a design by a realistic evaluation of those requirements.

Magnitude of Pitch-Change Rates

As pointed out previously, the magnitudes of pitch-change rates required by large rapid throttle transients

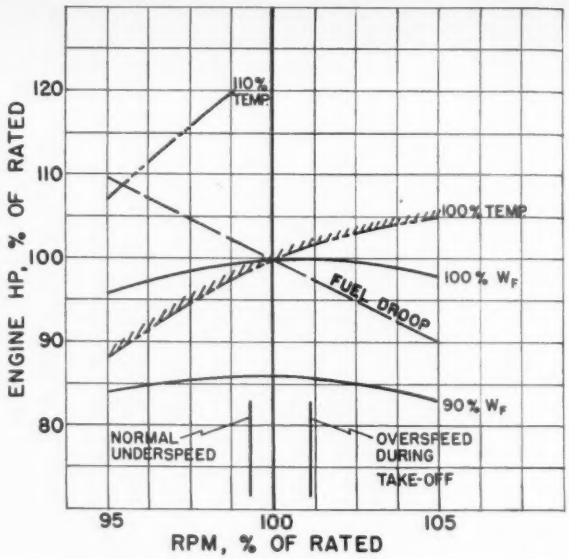

Fig. 6. Expansion of rated power area of 100 m.p.h. engine curve.

at low air speeds are several times those required by aerodynamic transients. This is more completely illustrated by Fig. 7. This figure shows the rate of pitch change required to accommodate the maximum rate of load change normally applied to the propeller versus air speed. The lower curve gives the pitch-change rates required to change load in keeping with aerodynamic variations applied at the maximum normal rate. The upper curve shows the rates required to accommodate a full throttle burst applied in 2 sec. on a typical installation. It is obvious from Fig. 7

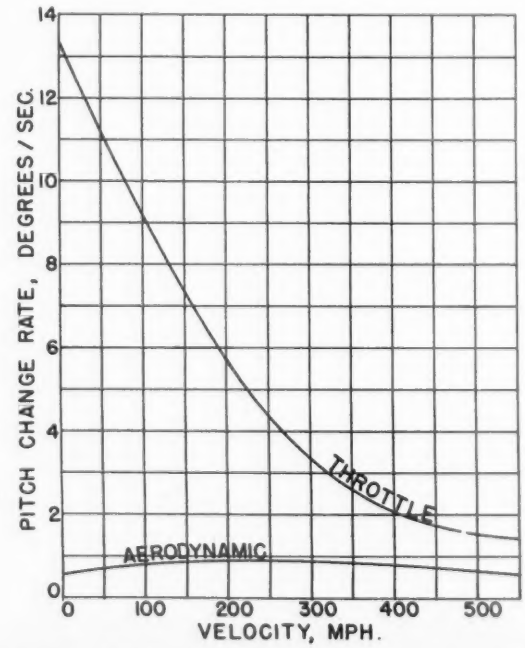

Fig. 7. Pitch-change rates required for throttle and aerodynamic transients.

that rates in excess of about 1 or 2 deg. per sec. are necessitated only by throttle changes at low velocities and not by aerodynamic requirements.

This would lead us to question the need of the one- and two-second throttle bursts presently considered as a design requirement. This is especially true when we consider that the ability of the propeller to change pitch rapidly is not always desirable. The severity of the thrust reversal accompanying a turbine-engine failure is well known. A low rate of propeller pitch change would delay the loss of positive thrust and the onset of reverse thrust following an engine failure. This delay could be valuable in providing time for the operation of emergency equipment. It could also provide more time for pilot action in maintaining control of the airplane.

What, then, can be done to reconcile the two conflicting requirements of high pitch-change rates to accommodate rapid throttle transients as opposed to the safety advantages of the low pitch-change rates?

First, it is recommended that the services and the aircraft and engine manufacturers consider the rapidity of throttle movement required in a given design in the light of the above factors. No limitation on the pilot's ability to move the throttle is anticipated; rather, a lag between this motion and the actual application of fuel to the engine is the solution considered. Present engines are in some cases operating under the paradoxical circumstance of applying fuel rapidly and then reducing it by means of a fuel overspeed governor during the resulting overspeed. It is beyond the scope of this paper to attempt to demonstrate the effect of the proposed lag on the take-off capabilities of a given airplane; it is felt, however, that the effect on the overall take-off picture would be small. The only loss would be during the transient occurring prior to establishing the quasi-steady-state take-off condition already described in detail.

Secondly, some consideration of new concepts of propeller control is in order. It is conceivable that the optimum propeller from the standpoints of adequate governing and of maximum flight safety might be one in which high pitch-change rates are available during a throttle burst but are severely limited when the throttle is at or near the full position. Such a propeller might even incorporate some means to prevent its reducing pitch entirely when the throttle is at the take-off position. In addition to take-off and climb, the more advanced throttle positions represent higher velocity flight conditions where less pitch-change rate is required for normal operation and high rates can cause severe thrust reversals rapidly.

High rates at very low throttle settings at low velocity, such as the landing approach, are not too critical, since a proper selection of the flight low-pitch stop aids somewhat the condition of engine failure under these circumstances. It might be noted that here again the engine characteristics are a large factor in the ability to select this stop for maximum protection and to provide it with a minimum of complexity.

One of the advantages of the torque type of control is that the propeller increases pitch following an engine failure and eventually feathers itself without sustaining reverse thrust.

It appears, in retrospect, that the engine characteristics contribute much to the determination of the propeller-control parameters, just as do these parameters in the determination of the engine's ability to provide maximum output. The obvious conclusion is not a new one. The optimum power-plant installation will always be the one in which the various phases of the installation are considered in the light of each other early in the project. Experience has proved that the operational problems cooperatively discussed early in the turboprop program were satisfactorily solved. Other factors, predetermined without considering the overall picture, have led to operational problems and difficulties.

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Structural Analysis of Swept, Low Aspect Ratio, Multispar Aircraft Wings

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SUMMARY

The assumptions of the bending and torsion theory of beams are revised in order to develop a "wide beam theory" applicable to swept low aspect ratio wings involving a large number of cells, ribs, and spars running in various directions. Loading conditions imposing only minor chordwise bending upon the structure are considered. For such conditions the equilibrium equations for bending moment and torque in chordwise cross sections yield two linear ordinary differential equations for deflection and twist of the structure, analogous to those known as "simple beam formulas."

By accounting properly for the effect of sweepback and chordwise spacing of the spars, new structurally significant cross-section properties are derived representing the effect of differential bending in wide beams and of cross coupling of torsion and bending due to sweepback. In addition to the conventional bending and torsional inertia, these properties give a more complete physical understanding of the structural behavior of low aspect ratio wings. A typical application of the theory for a parameter study is presented.

A numerical method to solve the structural differential equations for arbitrary coefficients is mentioned and applied to a delta wing test model. Comparison with test results shows satisfactory agreement of theoretical and test data.

LIST OF SYMBOLS

x, y, z	=	coordinates
w	=	deflection of elastic surface
f	=	deflection of elastic surface at $y = 0$
θ	=	angle of twist
α	=	angle between spar direction and x-axis
I_{B_i}	=	bending inertia of spar i
I_{T_i}	=	torsional inertia of cell i
E	=	modulus of elasticity
G	=	modulus of shear
M	=	bending moment
S	=	shear
T	=	torque
W	=	bimoment

The remaining unconventional notations used in this report are explained in detail within the text.

(1) INTRODUCTION

A MULTISPAR-MULTIRIB AIRCRAFT WING, as shown in Fig. 1, gives rise to a structural problem of high order redundancy. For a limited number of spars and ribs, this problem can be solved by the conventional methods of least work analysis or related methods, computing the redundant interactions between spars, ribs, and torque cells.

It is found in practice that the amount of work involved in setting up and solving a large number of simultaneous equations usually is prohibitive. This holds especially true in the preliminary design stage of an airplane, where the cross-section properties, as well as the external loads determining the coefficients of the equations, are subjected to severe and frequent changes. On the other hand, application of "simple beam" formulas may lead to an inefficient basic layout of the structure, difficult to improve upon in the final design stages.

These formulas deal with structural elements considered as "one-dimensional"—i.e., both width and thickness are assumed to be small compared with the length.

The structure of modern low aspect ratio wings often differs considerably from a simple beam. This fact is due to two reasons:

(1) The width of the structure (chordwise extension) cannot be assumed as being small compared with the length (spanwise extension). Therefore, the bending stiffness may not be considered concentrated in the "elastic axis" of the structure, and *differential bending* is to be taken into account.

By differential bending (sometimes also referred to as "torsion bending") is meant that different spars spaced in chordwise direction may bend differently.

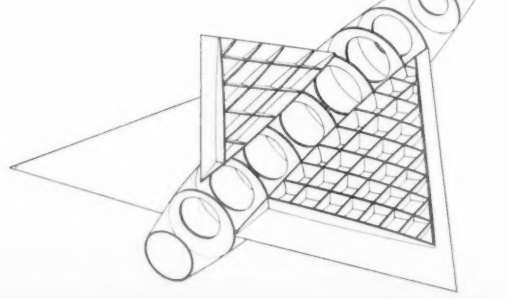

FIG. 1. Typical multispar structure.

Presented at the Structures Session, Annual Summer Meeting, I.A.S., Los Angeles, July 16–18, 1952.

* Engineering Department.

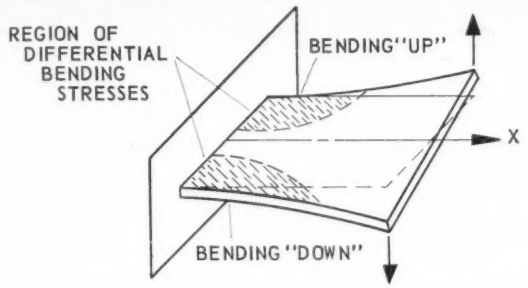

FIG. 2. Differential bending of a straight cantilever structure.

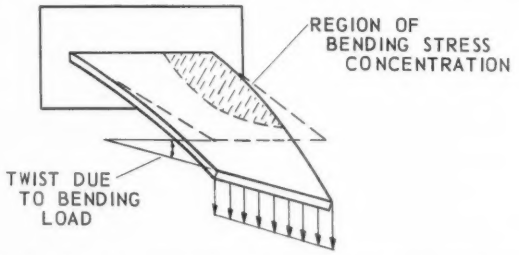

FIG. 3. Cross coupling of torsion and bending in a swept cantilever structure.

In a case of predominant torque, spars located in the region of the trailing edge of the wing may even bend in opposite direction from those located in the region of the leading edge. (See Fig. 2).

As a consequence of differential bending, originally plane cross sections will not remain plane after the deformation of the structure, as assumed by the conventional simple bending theory, nor will the warping of the cross sections remain entirely unrestrained as assumed by the simple torsion theory. Furthermore, the considerable width of the structure may give rise to *chordwise bending*. In general, there will be no specified direction parallel to which bending of the structure does not occur.

(2) Sweepback of high-speed wings and swept spars and stringers within the wing give rise to *cross coupling of torsion and bending*—i.e., deflection of the structure due to torque, and twist due to bending.

Therefore, a general elastic axis in its conventional sense does not exist—i.e., there is no axis at which any spanwise shear load distribution may be applied without giving rise to twist of the structure. Also, no general axis of rotation can be established as this axis changes its location for different torque distributions along the span.

Differential bending and cross coupling are illustrated with two cantilevered, simplified structures in Figs. 2 and 3.

Fig. 2 shows differential bending of a cantilever structure subjected to a torque applied at the tip. The bending deformation of the spanwise edges of the structure due to nonuniform rate of twist indicates the presence of bending stresses neglected by the simple torsion theory.

Fig. 3 illustrates the cross coupling between torsion and bending in a swept cantilever wing subjected to a shear load applied to the tip.

The twist of the structure due to cross coupling gives rise to the well-known effect of bending stress concentration toward the trailing edge of the structure.

Differential bending, chordwise bending, and cross coupling are neglected by the conventional beam theory. For many practically important loading conditions, however, chordwise bending may be considered as an effect of minor importance. It appears, therefore, possible to revise the assumptions of the conventional beam theory in order to make it applicable to the type of structure considered in this report.

By retaining the general concepts of axis, cross-section, and spanwise continuity, a theory of wide beams can be developed which can account for the effects of differential bending and cross coupling, without leading to excessively elaborate numerical work.

The same structural equations as developed have been derived in references 1–4. The philosophy of approach in these papers, however, is a different one. Essentially continuous structures of solid plate or sandwich-type construction are analyzed. To this end, the partial differential equation relating load and deformation is first derived. In order to obtain solutions, the deformation or the structure is expressed in the form of a power series:

$$w = a_0 + a_1 y + a_2 y^2 + \ldots$$

The assumption of "no chordwise bending" corresponds to taking only the two first terms of this power series into account.

(2) Assumptions

Fig. 4 shows an idealized, typical, multispar structure, as considered in this report. Such a structure may consist of any number of spars, running parallel or

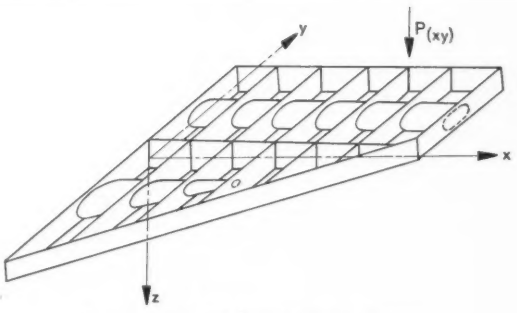

FIG. 4. Simplified multispar structure.

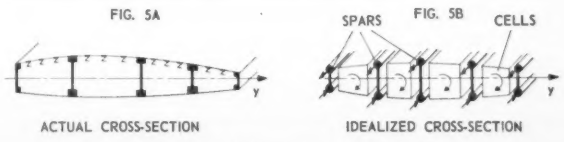

FIG. 5A (*left*). FIG. 5B (*right*).

forming various angles with the spanwise direction (x-axis). The spars are interconnected by a large number of chordwise ribs, running perpendicular to the span and parallel to the y-axis. Located in the bays of this gridwork of bending elements are torque cells, simulating the effect of a multicell box, formed by skin and spar webs.

The actual cross section (Fig. 5A) thus shall be considered as being built up by a finite number of spars with concentrated flanges carrying bending stresses in various directions and a number of cells carrying no axial forces but circulating shear flow only (Fig. 5B). It may be noted that the spar webs are, in reality, identical with the side walls of the cells.

For this structure, the following assumptions shall be made:

(1) The conventional assumptions of the simple beam theory shall hold for the individual bending and torque elements (spars, ribs, and cells) within the structure.

(2) The load carried by the structure shall be such as to produce only minor deformation of the chordwise sections. Therefore, bending of the ribs in their own plane shall be considered as an effect of minor importance.

(3) The thickness of the structure shall be small. Therefore, the shear deformations in the rib and spar webs and of the torque cell shall be considered as of minor importance for which approximate methods of analysis are satisfying.

(3) General Outline of Method

In order to develop a "wide beam theory," the following concepts of the conventional simple beam analysis will be adopted:

(1) A spanwise and a chordwise *axis* forming right angles are specified for the structure. The chordwise axis will usually be identical with the axis of symmetry of the airplane.

(2) *Cross sections* of the structure in chordwise direction are used as reference for deformation and structural parameters (cross-section properties). Equilibrium conditions for external and internal bending moments and torques acting upon the same cross sections are used in order to formulate the structural equations relating deformation and load of the structure.

(3) The structure is assumed to be continuous in *spanwise* direction. Thus, equilibrium equations can be specified continuously along the span, and the ensuing structural equations can be written in the form of differential equations. The number of ribs is assumed to be large enough so that the effect of finite rib spacing can be neglected.

By neglecting transverse bending, the elastic deformation of the structure can be described by two functions of the span x—deflection $f_{(x)}$ and angle of twist $\theta_{(x)}$. The derivatives of these functions can therefore be used to specify the curvature of any one spar at any point, as well as the twist of the torque cells. From curvature and twist, local bending moments and torques carried by the spars and cells can be computed.

The summation of local bending moments and local torques over a cross section must equal the external total bending moment and torque in order to satisfy equilibrium conditions. Thus, two simultaneous structural equations will be obtained for the cross section, relating external bending moment and torque with the deformation of the structure.

So far, the procedure is analogous to the one adopted by the conventional beam theory. The difference in the resulting equations is due to the fact that the local curvature of the structure is not assumed constant for a given cross section. Consequently, from these equations, new structural cross-section properties are defined, in addition to the well-known bending inertia, torsional inertia, and location of shear center. These additional cross-section properties describe the differential bending and cross-coupling behavior of the complex structure in much the same way as elastic axis, bending moment, and bending inertia describe the bending behavior of a simple beam.

For the sake of convenience, the two simultaneous differential equations can be reduced to one single equation, containing only the rate of twist as a dependent variable. To this equation, the equation of twist, a finite difference method is applied in order to obtain numerical solutions for a given problem. From the rate of twist, it is possible to compute the deflection by simple substitution and numerical integration.

With the elastic surface known, the local curvature and twist can be computed and the distribution of local bending moments and torques in each cross section specified. Therewith, the structural problem "determination of internal stress distribution due to a given external load" is solved.

From the rate of change of bending moments and from the torsional shear flows, the shear in the spar webs can be computed by superposition. Dropping the assumption that those webs are rigid in shear, the shear deformation in the webs can now approximately be computed. If the shear deformation is found to be sufficiently small, which is usually the case, the distribution of shear forces within the structures can be assumed to remain unaffected by this shear deformation. It is in this case permissible to consider shear deformation in the webs as a secondary, additive effect.

In a similar way, the effect of rib bending may be estimated. The external load can be represented by a set of concentrated forces acting upon the panelpoints (intersections of spars and ribs). If the shears in the spar webs are known, the shear in the rib webs can be computed by considering the vertical equilibrium condition for the panelpoints. The rib shear thus obtained would be carried by an infinitely rigid rib. Since the rib is, in fact, flexible, it will bend. If this bending of the ribs does not alter the shear distribution in the spars considerably, it may be considered as a "secondary effect," comparable to the one due to web shear deformation.

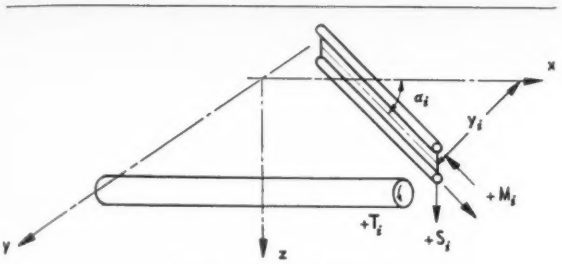

FIG. 6 Sign conventions.

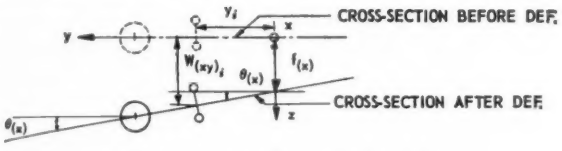

FIG. 7. Cross section before and after deformation.

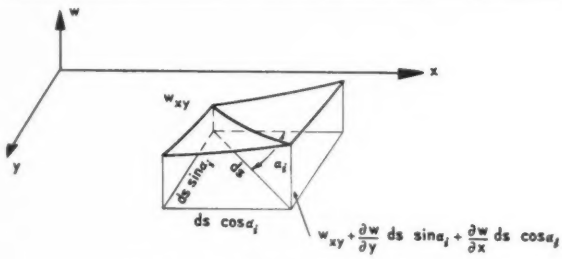

FIG. 8. Element of elastic surface.

(4) THE STRUCTURAL EQUATIONS

Fig. 6 shows the multispar structure considered, reduced to one typical spar and one tube, as well as the system of coordinates and the sign conventions used for bending moment M, shear S, and torque T.

The x-axis will be used as a spanwise reference axis for load and deformation parameters; the y-axis determines the direction of the transverse cross section for which equilibrium equations will be specified.

According to the condition "no rib bending," the displacement of a transverse cross section can be described by the deflection $f_{(x)}$ at the reference axis and angle of twist $\theta_{(x)}$, both being functions of the span x only (Fig. 7).

The displacement w_{xy} of a spar i is given by

$$w_{(xy)_i} = f_{(x)} + y_i\,\theta_{(x)} \tag{1}$$

whereas the rotation $\theta_{(x)}$ is constant for the whole cross section.

Eq. (1) describes the elastic surface of the structure. In order to obtain the local bending moment M_i of the spar forming an angle α_i with the x-axis, it is necessary to find the curvature of the elastic surface in the direction α_i.

Fig. 8 shows a differential element of a surface described by its ordinate w_{xy} (distance of the surface from the x-y-plane).

Applying the rules of differential geometry, the curvature of the surface in direction α_i can be expressed by

$$\left(\frac{d^2w}{ds^2}\right)_i = \frac{\partial^2 w}{\partial x^2}\cos^2\alpha_i + 2\frac{\partial^2 w}{\partial x\,\partial y}\cos\alpha_i \sin\alpha_i + \frac{\partial^2 w}{\partial y^2}\sin^2\alpha_i \tag{2}$$

Using the prime ($'$) for the differential operator d/dx, we obtain from Eq. (1) by partial derivation

$$\left.\begin{aligned} \partial^2 w/\partial x^2 &= f'' + y_i\,\theta'' \\ \partial^2 w/\partial x\,\partial y &= \theta' \\ \partial^2 w/\partial y^2 &= 0 \end{aligned}\right\} \tag{2a}$$

The curvature $(d^2w/ds^2)_i$ is related to the bending moment M_i by the simple beam formula

$$M_i = -(d^2w/ds^2)_i\,EI_{B_i} \tag{3}$$

Where EI_{B_i} is the bending stiffness of the spar i. Substituting Eq. (2) and the derivatives of Eq. (1) into Eq. (3), we obtain

$$M_i = -EI_{B_i}[(f'' + y_i\,\theta'')\cos^2\alpha_i + 2\theta'\cos\alpha_i \sin\alpha_i] \tag{4}$$

The shear transmitted by the spar is by definition

$$S_i = dM_i/ds = M_i'\cos\alpha_i \tag{5}$$

The simple torsion formula relates rate of twist and torque carried by a cell:

$$T_{S_i} = GI_{T_i}\,\theta' \tag{6}$$

where GI_{T_i} is the torsional stiffness of the tube i.

The notation I_T for the torsional inertia instead of the conventional J is used to indicate that this inertia is obtained by neglecting the shear deformation of the "sidewalls," which are identical with the spar webs. This assumption is necessary in order to obtain a physically consistent system.

The total bending moment and torque transmitted by a cross section containing n spars and m tubes can now be found by geometrical summation:

$$M = \sum_{i=1}^{i=n} M_i\cos\alpha_i \tag{7}$$

$$T = \sum_{i=1}^{i=m} T_{S_i} + \sum_{i=1}^{i=n} S_i y_i - \sum_{i=1}^{i=n} M_i \sin\alpha_i \tag{8}$$

Eq. (8) shows that the structure is able to carry torque by three different means: (1) by circulating shear flows in the skin $T_S = \sum T_{S_i}$; (2) by differential bending $T_{DB} = \sum S_i y_i$; and (3) by bending of swept spars $T\eta = -\sum M_i \sin\alpha_i$.

By substituting the quantities M_i, S_i and T_{S_i} from Eqs. (4), (5), and (6), two simultaneous linear differential equations will be obtained relating the deflection parameters with bending moment, torque, and cross-section properties.

By means of some algebraic operations, we obtain finally the "wide beam formulas" in a form convenient for numerical or analytical solution:

$$M = -EI_B\,(f'' + e\theta'' + 2\eta\theta') \tag{9}$$

$$T^* = GI_T{}^*\,\theta' - (EI_{w_0}\,\theta'')' \tag{10}$$

with the following notations:

Distance of cross-section centroid from the reference axis:

$$e = \frac{\sum I_{B_i} \cos^3 \alpha_i\, y_i}{\sum I_{B_i} \cos^3 \alpha_i}$$

Ratio of sweep:

$$\eta = \frac{\sum I_{B_i} \cos^3 \alpha_i \tan \alpha_i}{\sum I_{B_i} \cos^3 \alpha_i}$$

Effective bending inertia:

$$I_B = \sum I_{B_i} \cos^3 \alpha_i$$

Effective torsional inertia:

$$I_T{}^* = \sum I_{T_i} + (E/G)(4L - 2K')$$

Differential bending inertia:

$$I_{w_0} = \sum I_{B_i} \cos^3 \alpha_i (y_i - e)^2$$

Cross-section properties related to swept spars:

$$L = \sum I_{B_i} \cos^3 \alpha_i\,(\tan \alpha_i - \eta)\tan \alpha_i$$

$$K = \sum I_{B_i} \cos^3 \alpha_i (\tan \alpha_i - \eta) y_i$$

Effective torque:

$$T^* = T - (Me)' + 2M\eta$$

A structural quantity analogous to the bending moment M for differential bending is the "bimoment" W. W is defined as the "moment of the effective bending moments" with respect to the cross-section centroid:

$$W = \sum M_i \cos \alpha_i\,(y_i - e) \tag{11}$$

Substituting M_i from Eq. (4), and f'' from Eq. (9) we obtain

$$W = -EI_{w_0}\,\theta'' - 2EK\,\theta' \tag{12}$$

The boundary conditions for the equation of twist [Eq. (10)] can now be formulated.

(1) For the free (unrestrained) end of the wide beam, the bimoment W vanishes; therefore,

$$\theta'' + 2(K/I_{w_0})\theta' = 0 \tag{13}$$

(2) For the root of a rigidly built-in beam and for the axis of symmetry of a beam subjected to symmetrical loading conditions, the rate of twist vanishes and

$$\theta' = 0 \tag{14}$$

(3) For the axis of symmetry of a beam subjected to antisymmetrical loading conditions, the curvature of twist vanishes and

$$\theta'' = 0 \tag{15}$$

(4) For flexibly built-in structures, the amount of bimoment W acting between the beam and the support is a one-fold redundant quantity and can be computed by means of continuity considerations. After obtaining the redundant bimoment W, the boundary condition in terms of θ will be given by Eq. (12).

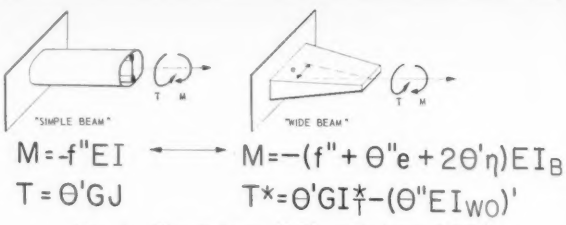

FIG. 9. Simple beam (*left*); wide beam (*right*).

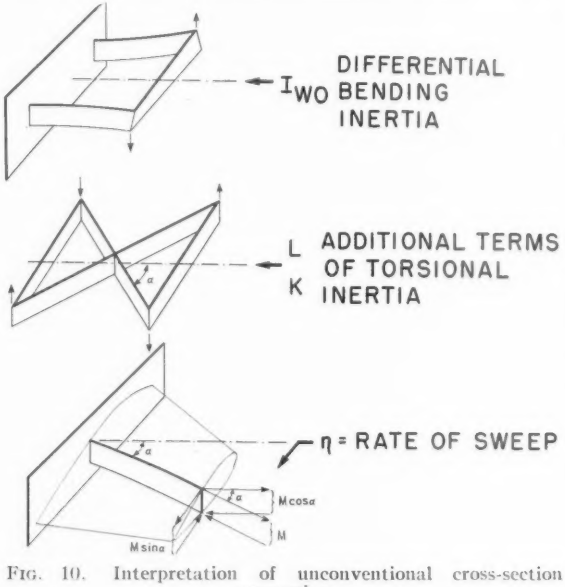

FIG. 10. Interpretation of unconventional cross-section properties.

Fig. 9 shows a comparison of a "simple beam" and a "wide beam" with the corresponding formulas.

A physical interpretation of the unconventional "cross-section properties" in Eqs. (9) and (10) is shown in Fig. 10.

The "differential bending inertia" I_{W_0} describes the ability of a wide, multispar structure to carry torque by differential bending.

The quantities K and L describe the ability of a structure consisting of crossed bending elements to carry torque.

The "ratio of sweep," η, describes the cross coupling between bending and torque, which is due to the fact that the bending moment in swept spars within the wing contains a component in the plane of the cross section contributing to the torque equilibrium [See Eq. (8)].

Solutions for Eqs. (9) and (10) can be obtained analytically if the coefficients are fairly simple functions of the span x. For a practical case, however, these functions are of an erratic type due to structural discontinuities. For such cases, a numerical finite difference solution, described in reference 5, has been applied, using IBM card programmed calculators. For a wing involving six spars, cross-section properties, de-

formation and bending moment, and shear distribution for a given loading condition have been calculated in approximately 4 hours machine and card-handling time.

(5) Applications

(*a*) *Parameter Study*

A typical result of a parameter study is presented by Figs. 11 and 12. A simplified delta wing of uniform thickness, built in at the centerline, is subjected to a uniform pressure p. The internal structure of this wing is assumed to consist of a large number of spars only, running either parallel to the trailing edge (Case A), parallel to the mid-chord line (Case B), or parallel to the leading edge (Case C). In any case, the total spar-cap material will be the same. According to the wide beam theory, these spars are assumed to be interconnected by a large number of rigid ribs running parallel to the centerline.

With these assumptions, deflection parameters and bending moment distribution have been computed. For a wing with a 60° leading edge, the results have been evaluated. The deformation of the cross section located at 0.75 semispan is plotted for the three spar angles in Fig. 11. The reversal in torsional deflection giving rise to opposite aeroelastic effects is remarkable.

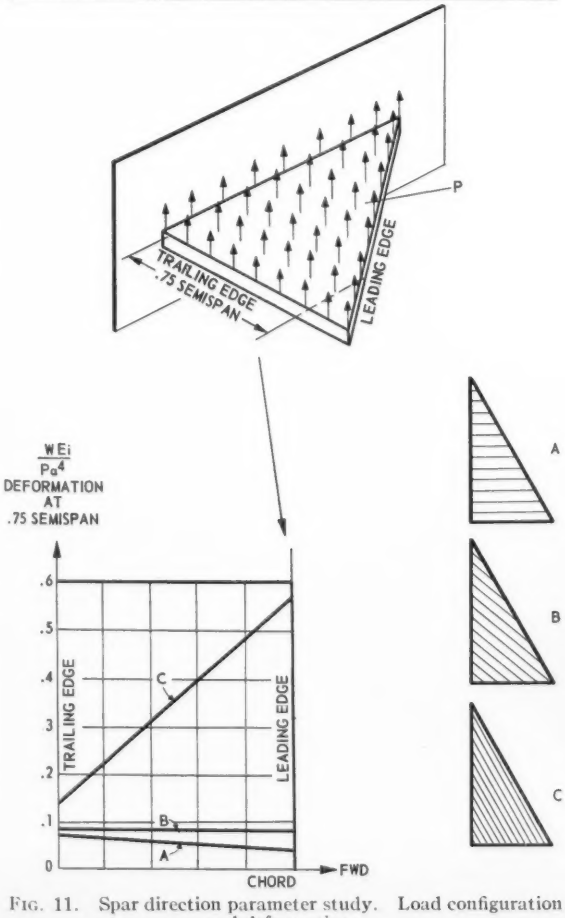

Fig. 11. Spar direction parameter study. Load configuration and deformations.

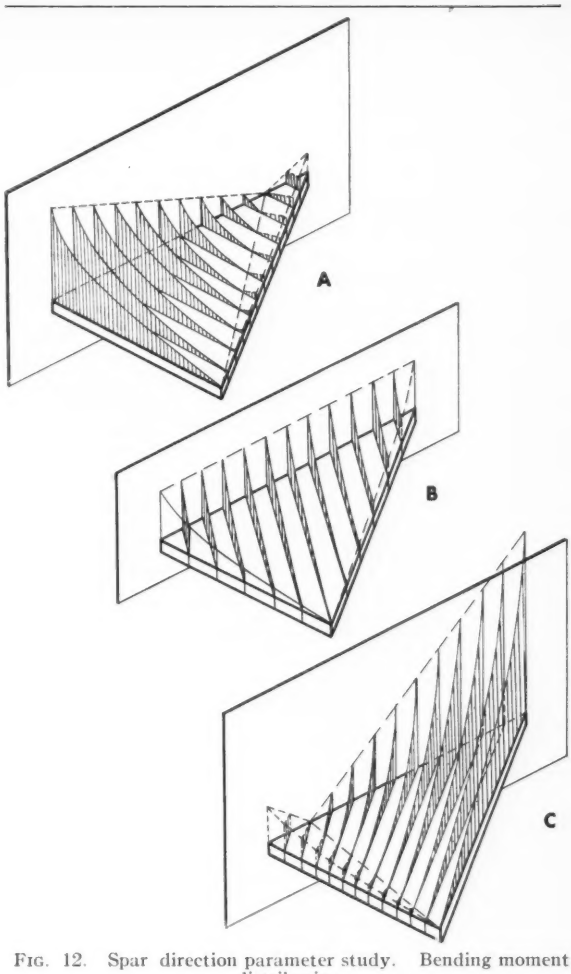

Fig. 12. Spar direction parameter study. Bending moment distribution.

Fig. 12 shows the bending moment distribution for the three spar angles. Whereas case A shows the expected stress concentration toward the trailing edge, case B shows no such concentration, and case C shows even a concentration at the leading edge. Similar results for deflection and stress distribution are obtained for typi-

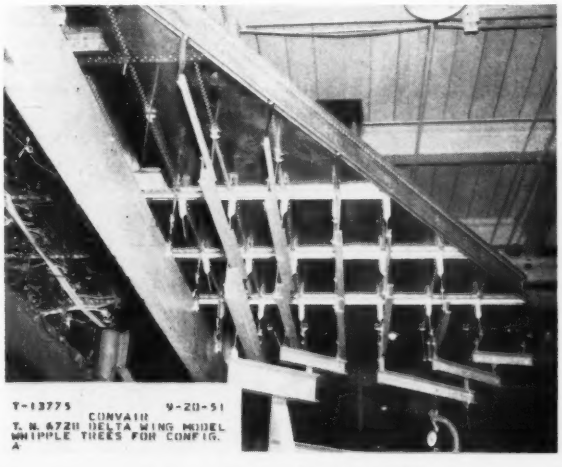

Fig. 13. Delta-wing test model.

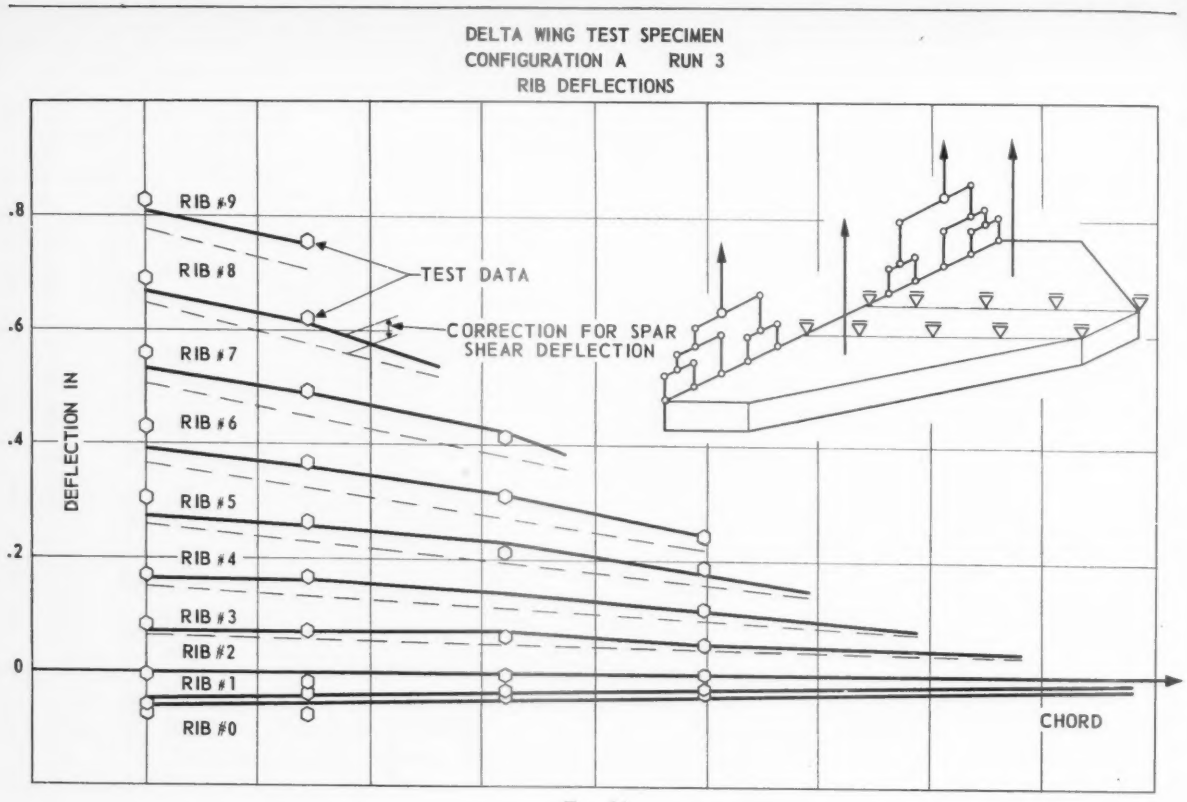
DELTA WING TEST SPECIMEN
CONFIGURATION A RUN 3
RIB DEFLECTIONS
RIB #9
RIB #8
RIB #7
RIB #6
RIB #5
RIB #4
RIB #3
RIB #2
RIB #1
RIB #0
TEST DATA
CORRECTION FOR SPAR SHEAR DEFLECTION
DEFLECTION IN
.8
.6
.4
.2
0
CHORD

FIG. 14.

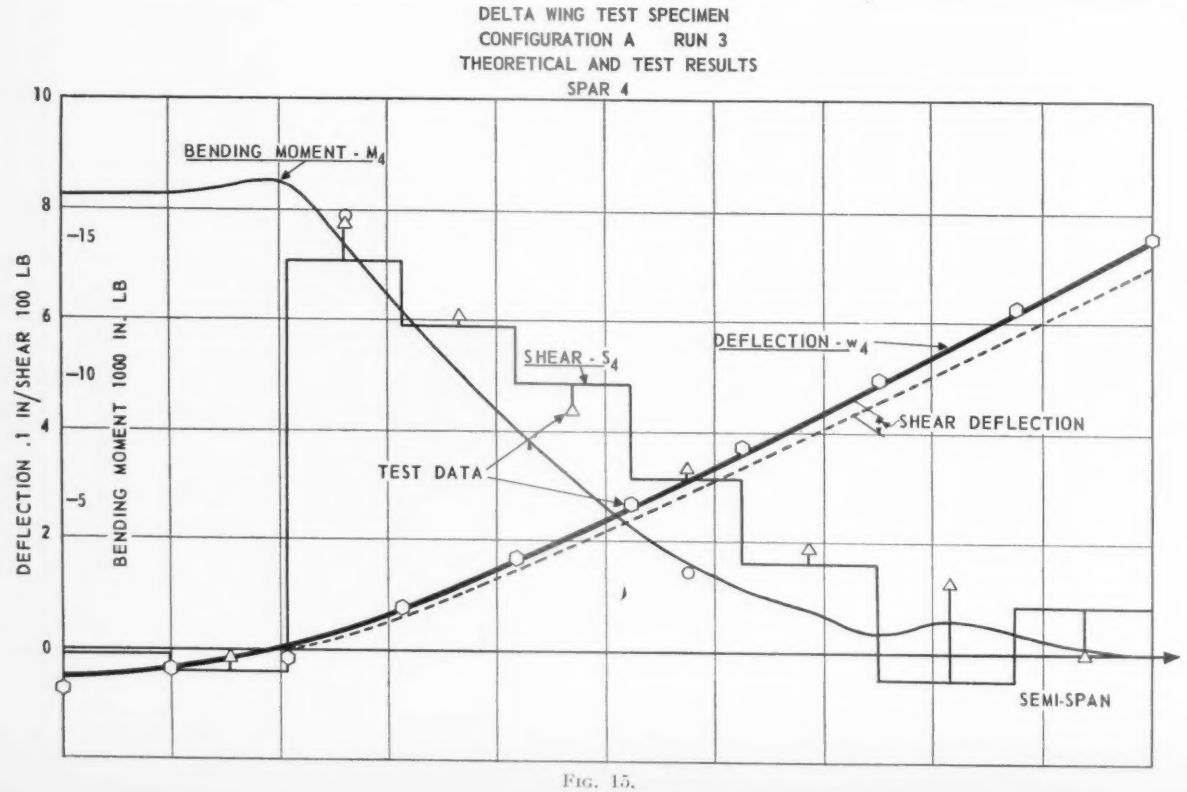
DELTA WING TEST SPECIMEN
CONFIGURATION A RUN 3
THEORETICAL AND TEST RESULTS
SPAR 4
BENDING MOMENT - M_4
SHEAR - S_4
DEFLECTION - w_4
SHEAR DEFLECTION
TEST DATA
DEFLECTION .1 IN/SHEAR 100 LB
BENDING MOMENT 1000 IN. LB
10
8
6
4
2
0
-15
-10
-5
SEMI-SPAN

FIG. 15.

cal elevon-load conditions (load concentrated at the trailing edge of the wing).

(b) *Comparison with Test Results*

A test model has been built by the test laboratory of Consolidated Vultee Aircraft Corporation, San Diego Division. Fig. 13 shows one-half of the test wing viewed from below, looking at the leading edge. The whipple tree shown in Fig. 13 is used to distribute the applied load between the panelpoints (intersection of spars and ribs).

For convenience of manufacturing, the wing has been built with constant thickness and external stiffeners. Taper of the structural properties is simulated by removable spar-cap doublers.

Details of the test model design and the full set of test data compared with theoretical results are reported in references 6, and 7.

Deflection and strain data have been obtained for a number of different cutout and support configurations and different loading conditions. The instrumentation consisted of 53 dial gages for deflection measurement and 206 strain-gage circuits for bending and shear strain measurement.

Theoretical data have been computed, using 20 equally spaced spanwise stations for the finite-difference approach mentioned in paragraph 4. All the arithmetical work involved has been performed on IBM equipment.

An example of the comparison between experimental and theoretical data is presented in Figs. 14 and 15.

Fig. 14 shows the type of load configuration and support of the wing, as well as the deflection data for all the panelpoints of the semiwing. The theoretical data, corrected for spar shear deflection, show excellent agreement with these test data.

Deflection, bending moment, and shear data for a typical spar are presented in Fig. 15. The shear data are plotted as constant averages for each spar bay between ribs.

The bending moments, based upon the 2 derivatives of the deflection parameters, show still reasonable agreement with the test data. The shear data, based upon 1 and 3 derivatives, show a more severe scatter that is partially due to numerical inconsistencies of the finite difference approach and partially due to the neglected effect of rib bending.

(6) Conclusion

In this paper, a method of structural analysis is presented for multispar aircraft wings. The deformation of the wing is first computed, using the assumptions that chordwise bending of the structure and shear deformation of the spar webs are negligible and that the structure is continuous in spanwise direction.

From the deformation, a logical distribution of bending moment, shear, and torque among the spars and torque cells within the cross section is derived.

The deformations obtained appear to be reliable for most practical loading configurations encountered in aircraft wings. Investigation of aerodynamic load redistribution due to elastic wing deformation and aileron reversal can be based safely upon those deformation data.

The shears become questionable at locations of spanwise discontinuities, where usually some chordwise bending occurs because of the shear transfer by the ribs. Furthermore, the finite difference method used to solve the structural equations gives rise to a numerical inconsistency if a low number of intervals is used in order to reduce the arithmetical work involved. Despite these shortcomings, the bending moment and shear data obtained for the spars can be considered adequate for parameter studies and for the type of stress analysis necessary to substantiate design decisions.

A more refined method is desirable for a final stress analysis and for the detail analysis of ribs and shear transmitting fittings. Such an analysis could possibly start from the wide beam analysis as developed in this report, refining the results by iterative procedures (relaxation methods). Another promising possibility consists in solving the redundant structural problem on hand by electric analog equipment or by a combination of such analog methods and numerical procedures.

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Fundamental Aspects of a Hydraulic-Type-Powered Flight-Control System*

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Purdue University

ABSTRACT

A typical hydraulic-powered flight-control system consisting of a bob weight on the control column to provide feel, mechanical linkages to a hydraulic control valve, and a hydraulic jack to actuate the control surface is described schematically.

Transfer functions for the various components of the control system are written, and the basic nonlinearity in the control valve is indicated.

It is shown that the control valve can be suitably represented by a linearization in which the rate of fluid flow through the control valve is taken proportional to the control valve displacement. Further, it is shown analytically that the linearization is valid over an extended frequency range that is determined from the characteristics of the control system load.

The linearization is also verified by experimental data obtained from frequency response studies on a model of the hydraulic components of the control system and the load.

It is shown that specifications for the hydraulic components depend upon a knowledge of the characteristics of the remainder of the control system including the dynamic characteristics of the airplane. Characteristics of a high-speed hypothetical airplane are used to implement the discussion, and the stability of the overall control system is discussed in terms of the Evans root locus plot.

Finally, a mechanical-hydraulic method of compensation is proposed which extends the stability range of the overall control system.

INTRODUCTION

THE INCREASED USE of powered flight-control systems with demands for more force amplification and higher response rates has focused attention upon problems associated with such systems. This paper deals with several of the fundamental difficulties encountered in the design and analysis of hydraulic powered control systems.

Since simplicity and dependability are paramount in aircraft design, it is important to understand why the additional complication of powered control systems has been accepted. Bollay,[1] in a comprehensive review of aerodynamic stability and automatic control, has indicated that transonic and supersonic speeds bring shifts in centers of pressure causing control forces that are larger than can be humanly overcome. In addition, maneuverability requirements of aircraft have increased with the result that human response time has become a limiting factor, hence, interceptors must rely more and more on automatic operation of some kind of powered control system. Lyons,[2,3] on the other hand, has indicated that the largest-size aircraft may require powered flight-control systems because of the large control forces associated with large size. However, the need for powered control systems is not so definite in this case since flight speeds will generally not be too high, and aerodynamic servotabs can be expected to be quite effective.

Admitting the necessity for powered flight controls, there remains the problem of selecting the physical means for effecting this control. The choice generally lies between mechanical-electrical or hydraulic systems, with combinations of the two a possibility. It is difficult to generalize on the comparative advantages and disadvantages of the two systems, and, in many cases, a selection of one in favor of the other may be based primarily on a better engineering understanding of the system favored. However, all other things being equal, it is felt that the two systems can be compared objectively on the following bases.

(a) Specific horsepower—i.e. control force rate per pound of control system.
(b) Rate of response.
(c) Inherent stability and ease of broadening the stability range.
(d) Mechanical efficiency.
(e) Simplicity and dependability, including ease of maintenance.
(f) Adaptability, for tie-in with automatic pilot, fire control, etc.
(g) Vulnerability.
(h) Cost.

It is obvious that comparison on the basis of so many factors will not lead to sharply drawn conclusions and that the choice, even for specific cases, will be the sub-

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ject for controversy. This is evidenced in the literature.

Comprehensive comparisons of airplane hydraulic and electrical systems have been presented by Bound[4] and Woodford.[5] These discussions were not limited to control systems but encompassed the entire scope of auxiliary devices, and, while not conclusive, the consensus can be summarized as follows.

Hydraulic-powered control systems are superior with respect to specific horsepower and rate of response. Their inherent stability is good, but, in cases where compensation is required, it is not easily effected.

The electrical-powered control system lends itself well to compensation, hence, its band of stability can be increased with relative ease. Its mechanical efficiency is superior to the hydraulic system, and, indeed, the heating in a hydraulic-powered control system can be a major problem. The electrical system is quite adaptable—e.g., it is easily linked to the autopilot. It is also possibly less vulnerable than the hydraulic system, although certainly this has not been definitely established.

Neither system has proved as simple or dependable as desired, and both have maintenance difficulties peculiar to themselves. Therefore, there is, at present, little to choose between the two on this basis.

Strangely, neither Bound nor Woodford mentioned the element of cost, apparently because of lack of reliable information on which to base a comparison. Obviously, this factor should not be overlooked.

The greatest incentives toward *study* of hydraulic-powered control systems are their preponderance on present aircraft and the fact that certain stubborn difficulties are being encountered. Therefore, and primarily for these reasons, our attention has been centered on the hydraulic system.

Scope of the Investigation

Primary emphasis in our work on powered control systems has been to establish and verify analysis procedures that will lead to synthesis of appropriate hydraulic components. It should be emphasized that our attention has been centered on the hydraulic portion of the system with stick and airplane dynamics thrown in to close the control loop. The ultimate goal of this effort is compilation of design principles that will specify what the hydraulic components can be expected to accomplish and how they must be designed for maximum utility.

However, in approaching this problem it has been impossible to ignore the fact that the dominant criterion is the performance and stability of the overall control system loop. We have, therefore, concurrently with a study of the hydraulic components carried along a study of methods of stabilization at high mechanical-hydraulic system performance—i.e., at high values of gain. One such method is presented in this paper. The next logical extension is the determination of requirements for compatibility of the control system with autopilot, fire control, the human pilot, etc., but no work in this direction can be reported on at present.

Our approach to the problem has been to write analytical expressions in linear form which, it is hoped, will describe the performance of the control system. There is essentially nothing new in these expressions, but, at the same time, there is little direct evidence presently available to support their validity. Therefore, a parallel experimental program has been undertaken to check the analytical statements.

The experimental program follows two lines. The first line attempts to correlate the descriptive relations that describe the hydraulic control valve characteristics with "static" tests involving rate of flow, pressure drop, and displacement of the control valve. This means that rate of flow and pressure drop must be correlated with valve geometry. A sizeable portion of the experimental work is devoted to this program.

In addition, the dynamic behavior of the hydraulic system is being studied experimentally by frequency-response measurements on a small scale rig that includes an aircraft-type control valve, hydraulic jack, pressure supply, and a fixed end beam to simulate the load. These experimental setups will be discussed in additional detail in subsequent sections of this paper.

Description of a Hydraulic-Powered Flight-Control System

The hydraulic-powered flight-control system, upon which attention is centered in the following pages, is illustrated in Fig. 1. It consists of the pilot control column with an attached bob weight to provide "feel" and mechanical linkages from the control column to a hydraulic control valve and a hydraulic jack that actuates the airplane control surface. The design is such that the deflection of the control surface is proportional to the movement of the control column.

The selection of the various components of this system depends upon specifications as to pilot preferences on stick force and travel, performance of the control system, and control surface forces and travel.

Definitive specifications of the mechanical part of the control system are generally based on a composite of pilot preference and human strength limitations.

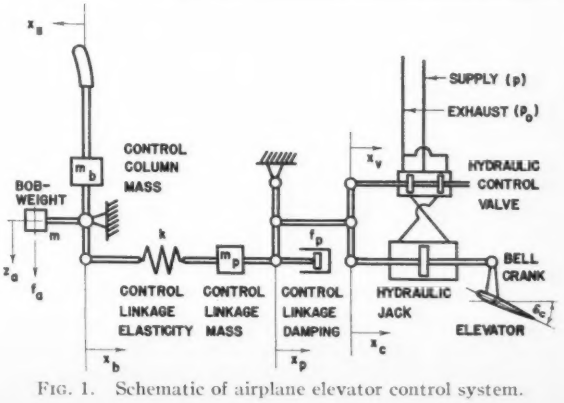

Fig. 1. Schematic of airplane elevator control system.

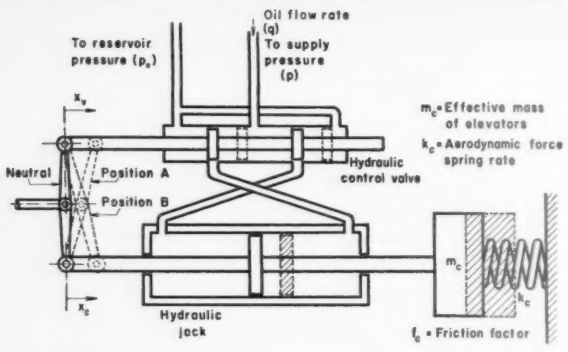

FIG. 2. Schematic of hydraulic components and control system load.

Orlansky[6] has reviewed available information on human pilot capabilities and preferences in which he indicates a wide diversity in both. Therefore, such specifications cannot be too rigid. In addition, there are elasticities, damping, and inertias associated with the control column and the various linkages which can only be specified within relatively broad manufacturing tolerances. For these reasons, the mechanical portion of the system is subject to few generalizations and must be subjected to close engineering study for each particular application. In this paper, reasonable average values will be used for the various parameters describing the mechanical portion of the system.

A bob weight has been selected for artificial feel primarily because of its simplicity. The use of the bob weight is based on the assumption that, in performing a pitching maneuver, the pilot *wants* to work harder to obtain higher vertical accelerations. Thus, it is assumed that the pilot wants a correlation between the force on the seat of his pants and stick force. Clearly, the bob weight is not the only means for obtaining such feel characteristics, but a detailed study of artificial feel mechanisms is not considered within the scope of this paper.

The mechanical portion of the control system ties directly into the control valve and hydraulic jack. A schematic of the hydraulic portion of the system, with a mass, spring, damper combination representing the control surface load, is shown in Fig. 2. The operation of the system can be followed closely in this figure. If the pilot presses on the control column, the linkage arm initially takes up position A because there is much less inertia and restraint associated with the control valve than with the hydraulic jack and control surface load combination. This motion of the control valve exposes the left chamber of the hydraulic jack to a high pressure supply of hydraulic fluid and the right chamber to a vented pressure reservoir. The tendency then is for the system to take up position B, thereby closing off the control valve and leaving the control surface deflected an amount proportional to the stick movement. The mechanical gearing of this system can be altered simply by changing the ratio of the control linkage lengths.

The deflection of the control surface (elevator) will cause the airplane to perform pitching motions, the nature of which will be determined by the control surface effectiveness and the dynamics of the airplane as a free body. If the control stick is free, the resulting acceleration force on the bob weight will tend to return the stick to its neutral position and, hence, to restore the airplane to equilibrium. Thus, the control system loop is "closed" and a dynamic analysis of the system can be carried out as with any analogous servomechanism circuit. This statement can be emphasized by means of the "block" diagram, Fig. 3.

In that diagram the input is the pilot force on the stick. Such a stick force results in a displacement, x_p, into the input linkage, the magnitude and phase of which is determined by the control stick dynamics. The displacement, x_p, is then converted to a control surface displacement, x_c, by the hydraulic power system and, through a bell crank, becomes an elevator displacement, δ_c. This results in airplane pitching motion through the airplane dynamics and, accordingly, in a vertical acceleration, ng, at the bob weight. The bob weight dynamics converts the load, ng, to a stick force F_a, and the difference between this force and the applied pilot force is the "error" of servomechanism terminology.

It is this system for which analysis methods will be presented in the following paragraphs.

Analysis of the Control System

Procedure

The methods of analysis which we have employed are familiar to servomechanisms engineers and have been reviewed by Bollay,[1] Moore,[7] and others. In addition, textbook treatments are becoming more and more numerous. Essentially, the approach has been to reduce the differential equations of each of the elements in the block diagram to operational form (Laplace transform) and thereby obtain the transfer function of each element. The composite transfer function can then be studied by any of several stability analysis methods, with our attention being devoted primarily to the Evans[8, 9] root locus method since it lends itself so well to synthesis. No attempt will be made here to review the various analysis methods, but rather the effort will be to motivate each step in the procedures as clearly as possible.

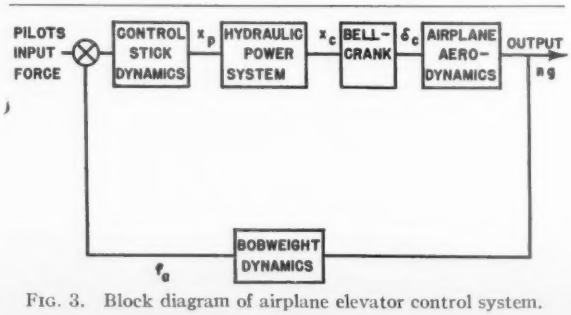

FIG. 3. Block diagram of airplane elevator control system.

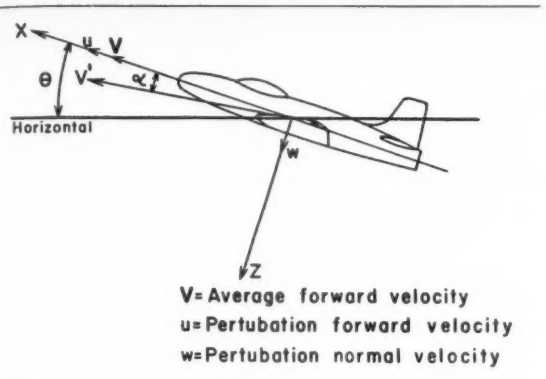

FIG. 4. Axes and nomenclature for airplane dynamics.

Control Column Dynamics

If a force F is applied by the pilot at the control stick, this is proportional to an acceleration, ng, applied at the bob weight with the stick free. This acceleration will result in a displacement, x_p, at the hydraulic end of the mechanical system, and a differential equation relating the bob weight acceleration force and the displacement can then be written. If the Laplace transform is then taken, one obtains an equation in the form

$$X_p/NG = K_p\, G_p(s) \qquad (1)^*$$

where K_p is the open loop gain, and $G_p(s)$ is the transfer function relating x_p and ng at all other values of frequency. s is the Laplace transform operator and both K_p and $G_p(s)$ are functions of the spring, mass, and damping factors in the system. Both K_p and $G_p(s)$ are subject to engineering revisions, but the approach here will be simply to evaluate these on the basis of reasonable parameter values when the need arises in a numerical example.

Airplane Dynamics

Proper choice of the airplane aerodynamics transfer function requires more extensive consideration. Discussion here will be restricted to longitudinal motion of the airplane, and it will be assumed that such motions are totally uncoupled from lateral motions. Following Jones and Briggs[10] the variables describing the longitudinal motion of the airplane are taken to be the perturbation angle of attack, α; the inclination of the flight path with the horizontal, θ; and $u' = u/V$, where V is the average forward velocity and u is the perturbation forward velocity. These variables are illustrated in Fig. 4. The equations of longitudinal motion of the airplane can then be expressed in the forms

$$\left.\begin{aligned} &(a_1 + a_2 s)A + a_4\,\textcircled{H} + a_7 U' = 0 \\ &b_1 A \qquad\quad + b_4\,\textcircled{H} + (b_7 + b_8)U' = 0 \\ &(c_1 + c_2 s)A + (c_5 s + c_6 s^2)\,\textcircled{H} + c_7 U' = d_1 \Delta_e \end{aligned}\right\} \qquad (2)$$

where again s is the Laplace transform parameter, and the coefficients a_i, b_i, and c_i are combinations of the longitudinal stability derivatives and the physical constants of the airplane. In general, these coefficients are functions of the average speed and altitude of the airplane.

It can be shown that the vertical acceleration of the airplane expressed in the above variables is given simply by $NG = Vs\,(A - \textcircled{H})$. Hence, if the input into the aerodynamic system is the control surface displacement, δ_e, then the transfer function for this element of the control loop can be written from the above equations as simply

$$\frac{NG}{\Delta_e} = \frac{Vs\,(A - \textcircled{H})}{\Delta_e} = K_e G_e(s) \qquad (3)$$

where again K_e is the loop gain and $G_e(s)$ is the frequency dependent transfer function, a function of the parameter s, the stability derivatives, and the physical characteristics of the airplane.

Hydraulic System Dynamics—Nonlinear Form

To complete the analytical description of the control system loop it is necessary to develop the transfer function of the hydraulic elements. This will be done in detail here and the experimental data presently available will be used to justify the transfer function finally selected as representative of the hydraulic components.

As indicated in a prior section, a displacement of the control valve, x_v, results in a pressure differential, p, across the piston in the hydraulic jack thereby causing a control displacement, x_c, in the same sense as x_v. If one assumes that the control valve is perfectly symmetrical and that there is zero overlap and underlap between the control valve piston and ports, the pressure difference across the jack piston is simply the supply pressure p_0 minus the pressure drop through the control valve, or

$$p = (\text{sign } x_v)\,[p_0 - C(q/x_v)^2] \qquad (4)$$

The right-hand side of Eq. (4) is multiplied by (sign x_v) to ensure that consistent signs occur; that is, that analytically a positive valve displacement results in a positive load displacement and, conversely, that a negative valve displacement results in a negative load displacement.

In the above form of the control valve equation, the reservoir pressure is assumed at atmospheric, and this is taken as the zero reference pressure. q is the volume rate of flow through the control valve into the hydraulic jack.

Strictly speaking Eq. (4) is valid only for rectangular ports in the control valve and the exponent factor, 2, is subject to experimental verification. Eq. (4) is plotted in Fig. 5 with p and x_v as ordinate and abscissa and q as parameter. It should be noted that both the x_v axis and the p_0 ordinate are limiting lines on this plot. The x_v axis is the locus of points along which the pressure drop across the valve is just equal to the supply pressure, and the p_0 line must correspond to a zero rate of flow. Flow conditions described by points exactly on

* Lower case letters denote the variables and capital letters their Laplace transforms.

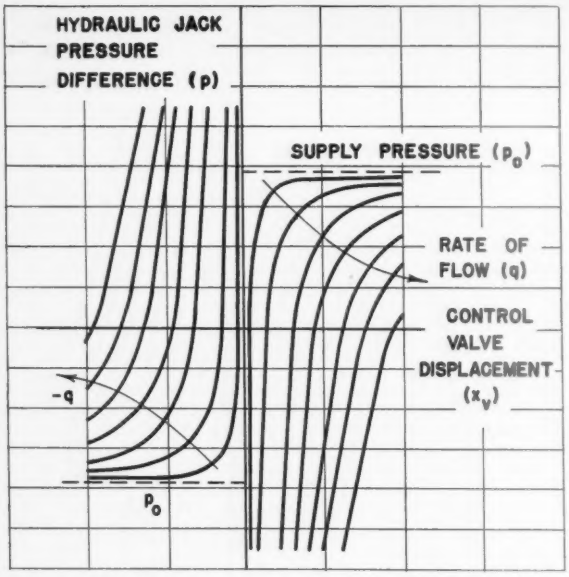

FIG. 5. Relation between pressure in hydraulic jack, rate of flow, and control valve motion. [Plot of Eq. (4).]

the x_v axis cannot be attained, since there is no pressure available to move the piston jack. We accordingly see that the control valve is inherently nonlinear in an extremely complicated way. However, there is another factor that lends additional complication to this equation.

The other factor referred to is the compressibility of the hydraulic fluid. The rate of flow, q, and the pressure difference, p, in the hydraulic jack can be related because of compressibility in the following manner.

First, if the fluid is assumed to be incompressible then the rate of flow into the hydraulic cylinder can be expressed by

$$q_{\text{inc}} = a(dx_c/dt) = a\dot{x}_c \tag{5}$$

where a is the interior cross-sectional area of the hydraulic jack. It can be shown that instability in the hydraulic circuit and control load loop can only occur if there are time delays between the motion of the control valve and the application of pressure in the hydraulic jack. This implies that the compressibility of the fluid must be considered, since, otherwise, the velocity of transmission of pressure signals is infinite.

Therefore, if it is assumed that the oil compressibility results in a spring rate of the jack piston, k_c lbs. per in., the rate of flow required to "compensate" for compressibility is

$$q_{\text{com.}} = \dot{p}a^2/k_c \tag{6}$$

so that the expression for the total rate of flow is

$$q = a\dot{x}_c + (\dot{p}a^2/k_c) \tag{7}$$

This means that q can be eliminated from the control valve equation, and the resulting form obtained is

$$p = (\text{sign } x_v)\left\{p_0 - C\left[\frac{a\dot{x}_c + (\dot{p}a^2/k_c)}{x_v}\right]^2\right\} \tag{8}$$

Now, aP, is the forcing function that results in the motion of the control surface. Hence, p can be expressed in terms of the load displacement, x_c, by the relation

$$aP = Z_c s X_c \tag{9}$$

where, again, this is the Laplace transform of the original differential equation, and Z_c is the impedance of the control surface load which can be written in terms of the effective inertias, damping, and spring constants of the aerodynamic system.

It is possible, at least in principle, to eliminate the pressure, p, by combining the differential Eqs. (8) and (9) and, thus, obtain a relationship between the control valve input, x_v, and the output, x_c. However, the result is a nonlinear equation to which the methods of linear synthesis cannot be applied. Therefore, the immediate problem is to determine a linear relationship that will approximately agree with Eq. (4).

To accomplish this, we return to Eqs. (4) and (7) governing the pressure, rate of flow, and the displacement variables in the hydraulic system. Linearization of the problem involves the determination of a linear relation between the variables p, x_v, and q which will approximately satisfy Eq. (4) over a sufficiently wide range of parameter values. Two possible linearizations will be discussed.

Linearization—Flow Proportional to Control Valve Displacement

This linearizing approximation can be motivated directly from an inspection of Fig. 5. If it is assumed that the load displacement, x_c, and its time derivatives are all small, then the forcing pressure, p, will be similarly limited, and attention can be centered on the low pressure region of Fig. 5. In this region the lines of constant rate of flow, q, are nearly straight and vertical and approximately evenly spaced for a reasonable range of control displacements, x_v. Therefore, these considerations lead to the investigation of the linear approximation

$$q = k_1 x_v \tag{10}$$

where k_1 is a constant adjusted to give correspondence with the graph at arbitrarily selected values of q and x_v.

On the basis of this approximation, the equations describing the hydraulic system-control load loop are

$$\begin{aligned} Q &= k_1 X_v \\ Q &= as\, X_c + (a^2 sP/k_c) \\ aP &= Z_c s\, X_c \end{aligned} \tag{11}$$

This system of equations can then be solved for the open loop transfer function X_c/X_v with the result

$$X_c/X_v = k_1/as[1 + (Z_c s/k_c)] \tag{12}$$

Note that for an incompressible fluid this reduces simply to

$$X_c/X_v = k_1/as \tag{13}$$

which states that the hydraulic system acts like a simple

integrator when the spring constant of the oil is much larger than the impedance of the control system load.

Effect of Load Impedance

Little additional information can be gained at this point by comparing analytically the above linear form with the nonlinear equations. However, additional insight into the basis for this approximation can be obtained in the following manner.

Suppose that we consider only Eqs. (7) and (9). If x_c is eliminated from these two relations, the ratio Q/P can be written in the form

$$Q/P = a^2[(1/Z_c) + (s/k_e)] \tag{14}$$

It is important to note that this relation must hold between Q and P regardless of the control valve characteristics.

Now if the load is assumed to consist of a mass, spring, damper combination, the load impedance Z_c can be written as a second degree polynomial divided by s. That is,

$$sZ_c = (s - \beta_1)(s - \beta_2) \tag{15}$$

Then the ratio Q/P can be written

$$\frac{Q}{P} = \frac{a^2 s (s - \gamma_1)(s - \gamma_2)}{k_e (s - \beta_1)(s - \beta_2)} \tag{16}$$

Following the method of Bode as reviewed by Bollay,[1] this equation has been plotted in Fig. 6 with the ordinate logarithm Q/P in decibels and the abscissa the logarithm of the frequency. For very low values of the frequency only the term $a^2 s/k_e \ \gamma_1\gamma_2/\beta_1\beta_2$ is important, which means that the asymptote to the plot rises with a slope of 6 db. per octave. It will continue to rise at this rate until the lowest natural frequency of the system is reached. Since the numerator of the expression contains the spring constant of the oil as well as that of the load, the lowest natural frequency will be given by the denominator, and, accordingly, the asymptote will then turn through 12 db. per octave and proceed downward from that point at the rate of 6 db. per octave. It will continue downward at this rate until the break frequency of the numerator is reached, at which point it will again proceed upwards at 6 db. per octave.

Certain facts are at once deducible from Fig. 6. In particular, assume that the valve motion is small enough so that the rate of flow is restricted to be less than some value q_m. This will then mean that the corresponding values of p will be given by

$$|P| \leqq |Q_m| \frac{1}{|Q/P|} \tag{17}$$

or

$$|P|_{\text{db.}} \leqq |Q_m|_{\text{db.}} - |Q/P|_{\text{db.}} \tag{18}$$

Specifically, if the amplitude of p is also restricted to be less than some value p_m, then the frequency range over which both restrictions are compatible can be obtained from

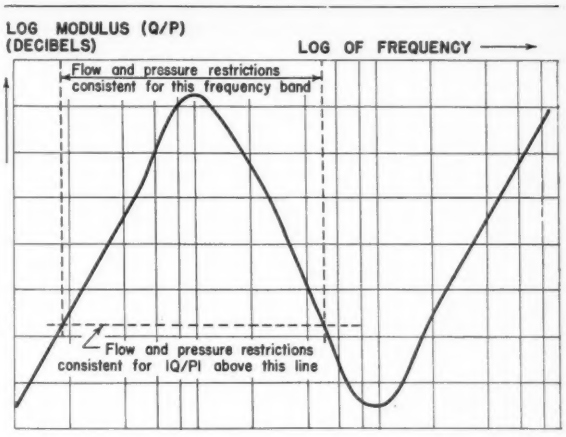

FIG. 6. Bode modulus-frequency diagram of the ratio (rate of flow/jack pressure).

$$|Q/P|_{\text{db.}} \geqq |Q_m|_{\text{db.}} - |P_m|_{\text{db.}} \tag{19}$$

This, in effect, defines a horizontal line as shown in Fig. 6 above which the restrictions are compatible, and the intersections of this line with the plot define the two frequency limits within which the restrictions are compatible.

The significance of this discussion can be seen if we again refer to the plot of the valve equation, Fig. 5. There it is seen that for reasonably small values of q and p, the curves are nearly straight and vertical. Fig. 6 then becomes important, since it allows one to determine whether the ranges of q and p thus selected will be compatible over a sufficiently large frequency range to cover the actual operation of the control system. Were this not so, it would indicate ranges of operation over which the approximation would not be descriptive of the actual system. The most important fact to be noted is that these conclusions cannot be reached unless the characteristics of the control system load are considered.

Linearization—Pressure Proportional to Valve Displacement and Rate of Flow

This assumption is essentially only an extension of the first. It is based on the fact that the pressure difference, p, across the jack piston depends upon the rate of flow, q, and the control valve displacement, x_v. Thus Eq. (4) is replaced by the first two terms in a Taylor's expansion,

$$p = (\partial p/\partial x_v)x_v + (\partial p/\partial q)\, q \tag{20}$$

where the partial derivatives are given values corresponding to arbitrarily selected points, x_v and q.

This extension recognizes that the lines of constant rate of flow in Fig. 5, while nearly straight for small values of p, are skewed considerably from the vertical even for relatively small values of x_v. Therefore, just an examination of the figure suggests that this linear approximation may be of the form

$$p = C_1 x_v - C_2 q \tag{21}$$

where C_1 and C_2 can be evaluated by matching this

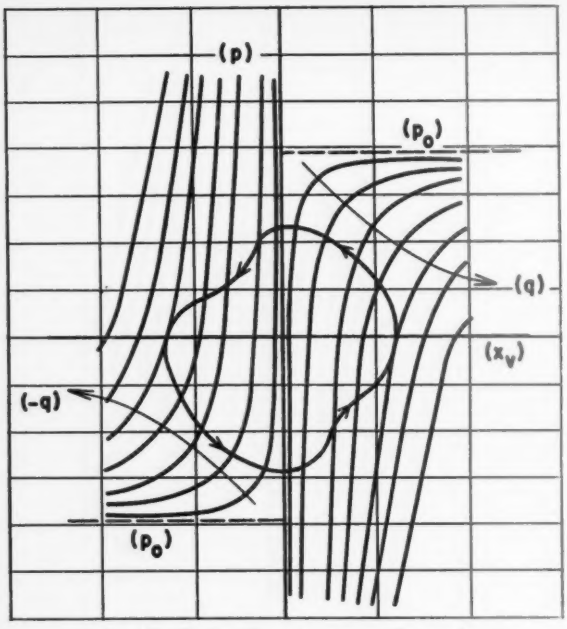

FIG. 7. Hydraulic system operating path.

family of straight lines to the plot in Fig. 5 at two points, and, of course, these constants are just the partial derivatives in the Taylor's expansion above.

If this approximation is employed, the equations governing the hydraulic elements and the load become

$$\left.\begin{aligned} P &= C_1 X_v - C_2 Q \\ Q &= asX_e + (a^2 sP/k_e) \\ aP &= Z_e s X_e \end{aligned}\right\} \qquad (22)$$

These equations can then be reduced to the open loop transfer function

$$\frac{X_e}{X_v} = \frac{C_1}{as\left[\frac{Z_e}{a^2} + C_2\left(1 + \frac{Z_e}{k_e}s\right)\right]} \qquad (23)$$

If the fluid is incompressible this reduces to

$$\frac{X_e}{X_v} = \frac{C_1}{as[(Z_e/a^2) + C_2]} \qquad (24)$$

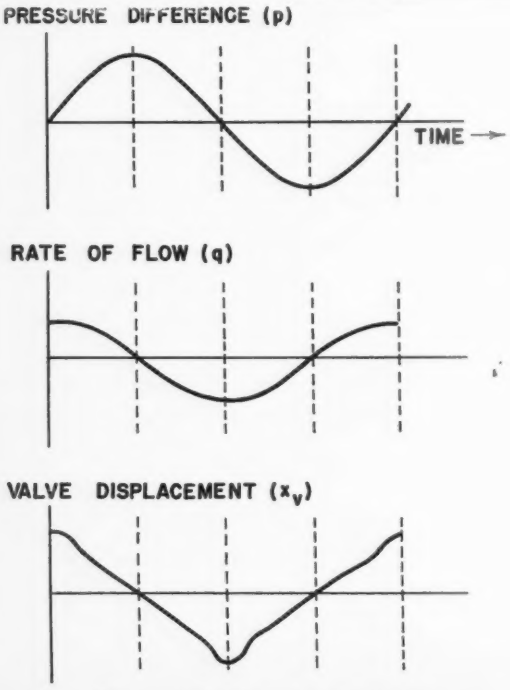

FIG. 8. Hydraulic system wave forms.

Wave-Form Analysis

The operation of any system can always be described by linear equations if the variations in the independent variables are kept sufficiently small. The basic engineering question is: Can a linear description of the system be found which is valid for significant or typical amplitudes of the input signals? The discussion on load impedance indicated the following fundamental fact.

A linear description of the control system (in particular, $q = k_1 x_v$) is valid over a determinable frequency range. The actual extent of this frequency range depends upon the characteristics of the control system load.

Further insight into the characteristics of such linear approximations is realized by a graphical analysis of the wave form at various points in the system. A direct analysis would involve the assumption of a sinusoidal wave form for the valve displacement, x_v, and the subsequent calculation of the associated wave forms of the rate of flow through the valve and the pressure drop across the jack piston. Analysis of this type entails a trial and error procedure. A simpler approach, yielding the qualitative information desired, involves the initial assumption of a sinusoidal wave form for the pressure drop across the piston. From the load characteristics, the corresponding wave form of q (also sinusoidal) is determined. The associated wave form of x_v is then found from the valve characteristics.

The general form the analysis takes is illustrated by Fig. 7. An operating path is plotted on the valve characteristics from the assumed value of p and the resulting values of q determined from the load characteristics. (If the valve characteristics were plotted as curves of p versus q with x_v the parameter, the operating path would be a simple ellipse.) Values of the parameter time, are marked along the operating path. The resultant wave form of x_v is then read directly from this graphical construction. A typical set of wave forms is shown in Fig. 8.

A complete evaluation of the linear approximation involves an analysis similar to that described above at a number of representative frequencies. The particular frequencies at which an analysis should be made can be determined by reference to a sketch of the form of Fig. 6. The wave form of x_v is nearly sinusoidal at frequencies for which the inequality, Eq. (19), is satisfied and deviates considerably from sinusoidal nature at frequencies at which Eq. (19) is not satisfied. A typical group of wave forms for x_v is shown in Fig. 9.

This waveform analysis must answer the following questions.

(a) Over what frequency range is the wave form of x_v suitably represented by a sinusoid?

(b) Over what part of the above frequency range is the amplitude of x_v suitably represented by a proportionality constant times the amplitude of q?

(c) How does the amplitude of q influence the answers to (a) and (b)?

Certain general comments can be made concerning this analysis.

(1) The zero crossings of x_v always coincide with those of q. Hence, in this "phase" sense, the linear approximation, $q = k_1 x_v$, is excellent.

(2) In the frequency range over which the analysis associated with Fig. 6 indicates that $q = k_1 x_v$ is valid, the wave form of x_v is very nearly sinusoidal. In this range, the wave form analysis essentially confirms the results stated from considerations of the load impedance.

(3) Even at frequencies considerably outside the band indicated by Fig. 6, the wave form of x_v is very nearly sinusoidal. The principal manner in which the approximation, $q = k_1 x_v$ seems to fall down here is in a change in the value of k_1. That is, the fundamental component of x_v is no longer exactly proportional to the amplitude of q.

(4) The effect of third harmonic distortion (the principal frequency component of the distortion) is decreased by the attenuation introduced by the rest of the system. In general, the system tends to integrate, with gain falling off inversely with frequency. Consequently, the gain for the already small third harmonic will be only about one-third the gain for the fundamental.

In summary of the above discussion concerning the approximation, $q = k_1 x_v$, for the valve characteristics, the following general statements can be made. The approximation is valid over ranges of amplitude and frequency which depend on the load characteristics. The approximation is definitely not valid at very low frequencies or at very high frequencies. For a typical aircraft hydraulic system with aerodynamical and mechanical load, the approximation is valid for control valve displacements of the order of 0.02 in. and over a band of frequencies from well below one cycle per sec. to a frequency in the order of 100 cycles per sec.—i.e., the approximation is valid in the frequency band of interest to the engineer for the design of both the hydraulic closed-loop system and the overall aircraft control system.

The last statement is significant in that it means the more detailed approximation, Eq. (21), need not be considered. Actually, the two approximations are nearly equivalent except at zero frequency, at which point neither approximation is valid, and, therefore, from an analytical standpoint, there is no reason for accepting the added complications associated with Eq. (21).

It remains now to present the experimental verification of the approximation, $q = k_1 x_v$.

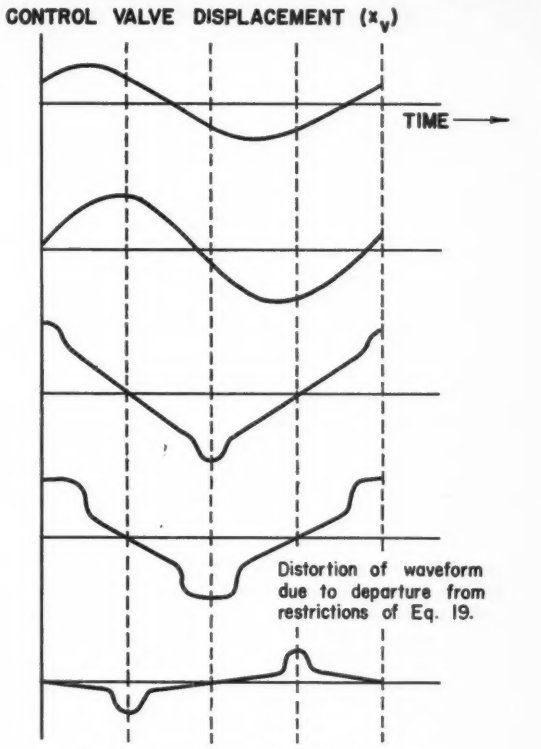

FIG. 9. Control valve input wave forms.

THE EXPERIMENTAL INVESTIGATION

Valve Static Tests

The first experimental work to be discussed here will be that concerned with the static performance of the valves.

The first valve tested was chosen on the basis of a valve type currently in use in aircraft control systems. Fig. 10 is a schematic of this valve showing pertinent dimensions. It is a slightly unsymmetrical valve and has a certain amount of overlap. In particular, there is a total displacement of 0.017 in. (0.006 in. to the left of neutral and 0.011 in. to the right of neutral) at which no flow can occur. The inlet ports are closed for a total displacement of 0.0062 in. (0.0031 in. on each side of neutral). It follows then that this valve is not properly described by Eq. (4) since that valve equation assumes complete symmetry and zero "overlap" and "underlap."

The static calibration equipment is shown diagrammatically in Fig. 11. The hydraulic circuit consists of

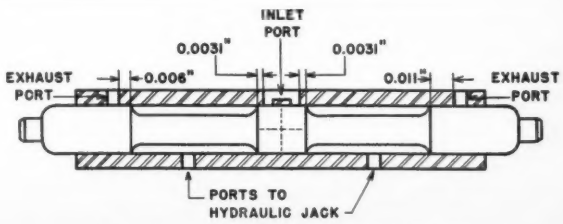

FIG. 10. Schematic of test control valve.

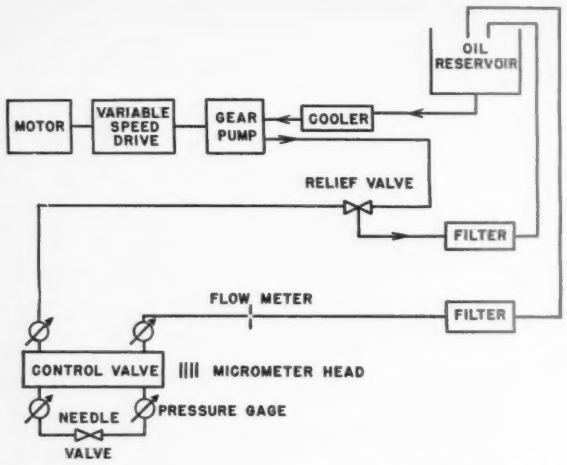

FIG. 11. Diagrammatic arrangement of static calibration equipment.

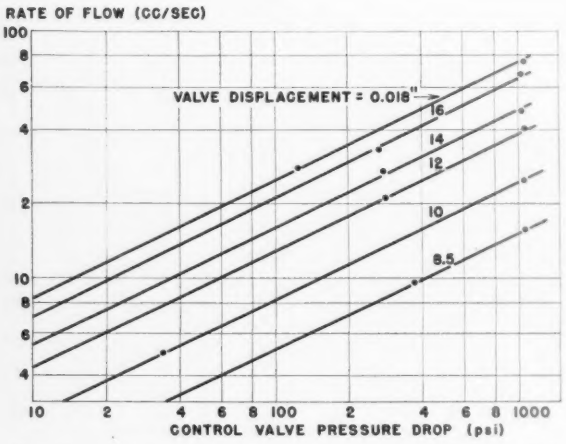

FIG. 12. Control valve flow rate versus pressure difference (left side of valve).

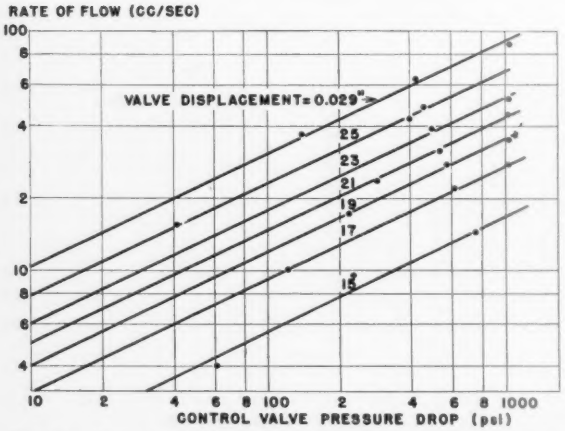

FIG. 13. Control valve flow rate versus pressure difference (right side of valve).

a motor driven Pesco positive displacement pump, relief valve, servo-valve, graduate for measuring flow, filters, oil reservoir, and cooler. The motor drives the hydraulic pump through a variable speed control in order to vary the output of the pump.

Adapters were made for the control valve connections so that static pressures could be measured as close to the valve ports as possible. Heise pressure gages were used to obtain the pressure readings, and valve piston displacements were measured with a micrometer head.

The general testing procedure was to record several flow rates and pressure drop readings at various displacement settings. The flow rates and pressure drops for a fixed displacement setting were varied by means of needle valve control.

The data thus obtained plotted on log-log scale are presented in Figs. 12 and 13 with flow rate as ordinate, pressure drop across the control valve as abscissa, and valve displacement as parameter. The average slope of these lines is 2.2 indicating that the exponent of 2, originally chosen for the valve equation, will describe this valve reasonably closely.

The data are also presented in Fig. 14 with flow rate as ordinate, valve displacement as abscissa, and pressure drop across the control valve as parameter. The data plot as a family of straight lines indicating that q and x_v are properly raised to the same exponent in the valve equation. The overlap and nonsymmetry of the valve are clearly evident in this figure.

The most important fact to be obtained from Fig. 14 (disregarding the overlap and nonsymmetry) is its relation to the linear approximations, Eqs. (10) and (21).

In order that Eq. (10) be exact, it would be necessary to have a valve in which all of the pressure lines coalesced into one straight line. This is clearly an impossibility. However, it should be possible to design valves in which these pressure lines are reasonably close over a fairly wide range of values of p. The approximation would then replace the family of lines with one line representing an average of the family.

The second approximation can, on the other hand, be written

$$q = (C_1/C_2)x_v - (1/C_2)p \qquad (25)$$

which says that for a given x_v, the rate of flow is decreased as p increases and at the same rate independent of x_v. Thus, this approximation replaces the fan of curves by a set of parallel lines which, on the basis of static tests, may be a good approximation if the variables are restricted to a small range of operation.

However, it should be emphasized that the principal reason for conducting the static tests is *not* to verify the validity of the linearizing approximations but rather to obtain a correlation between valve geometry and static characteristics. There is no presently determined basis for stating that such valves should be linear, and, indeed, there may ultimately be good reasons for designing definite nonlinear characteristics into the valves. When such knowledge is finally at hand it will

be extremely useful to be able to specify exactly how the valve should be designed to obtain the desired characteristics. Meanwhile, the tendency is to demand that the valves be as nearly linear as possible, since this removes one formidable difficulty in the analysis.

The validity of the linearizing assumptions can, however, be established on a model rig of the hydraulic components and the load. This has been done and can be reported on at the present time.

Model for Dynamic Simulation

The dynamic tests have been set up as follows. The model rig consists essentially of a hydraulic cylinder driving a fixed-end steel beam. The beam was selected to represent as closely as possible the effective inertia and stiffness parameters associated with airplane elevators. The hydraulic cylinder is actuated by a four-way control valve, and a mechanical linkage between this valve and the hydraulic cylinder is utilized to yield the proper relationship between the control valve displacement and the hydraulic piston displacement. Figs. 15 and 16 are pictures of the model as instrumented for the frequency response studies.

In conducting the tests, the input, x_v, to the control valve is given a sinusoidal motion by means of an electric motor driving a scotch yoke. The frequency is varied by changing the speed of the motor and the amplitude by changing cams in the scotch yoke. Linear differential transformers are used to follow this motion, as well as that of the output, x_c. The output from the linear differential transformers can either be read visually on an oscilloscope or can be taken as a permanent record by means of a Brush recorder. Thus, it is possible to obtain a phase and amplitude comparison of the variables x_v and x_c.

Results from Simulator

The impedance associated with the fixed-end steel beam can be expressed by

$$Z_c = m_c s + f_c + (k_c/s) \tag{26}$$

where m_c, f_c, and k_c are the effective inertia, damping, and spring constants of the beam. If Eq. (26) is substituted into Eq. (12) and the result rearranged, one obtains

$$\frac{X_c}{X_v} = \frac{k_1 k_c}{a m_c s^2 + 2\zeta\omega_n s + \omega_n^2} \tag{27}$$

where

$$\left.\begin{aligned} \zeta &= f_c/2\sqrt{m_c(k_c + k_e)} \\ \omega_n^2 &= (k_c + k_e)/m_c \end{aligned}\right\} \tag{27a}$$

A plot of Eq. 27 on a decibel-log frequency coordinate system results in a curve as shown in Fig. 17.

The characterizations of Fig. 17 are the 20-db. per decade slope below the break frequency, the break frequency ω_n, the 60-db. per decade slope above the break frequency, and the height of the curve above the zero

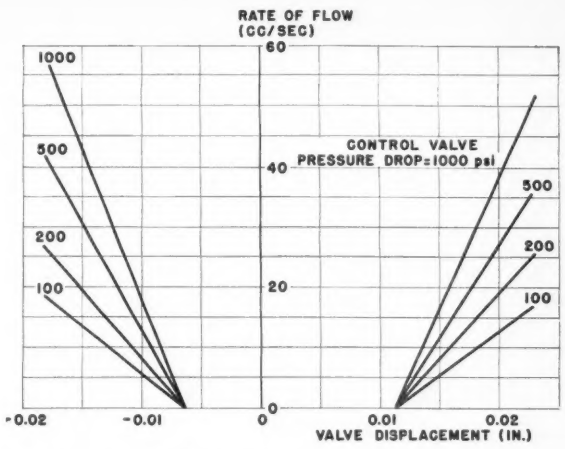

FIG. 14. Control valve rate of flow versus valve displacement.

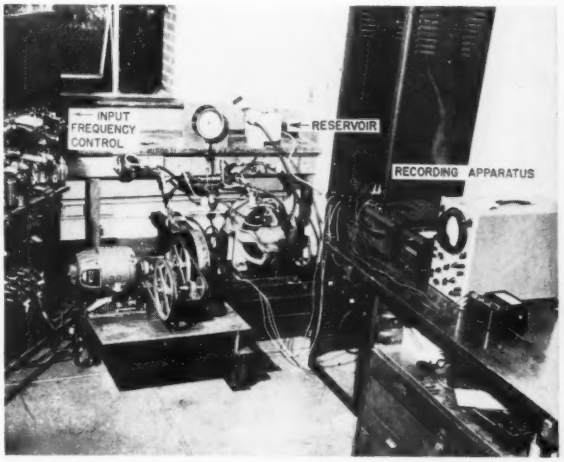

FIG. 15. Overall view of dynamic simulator.

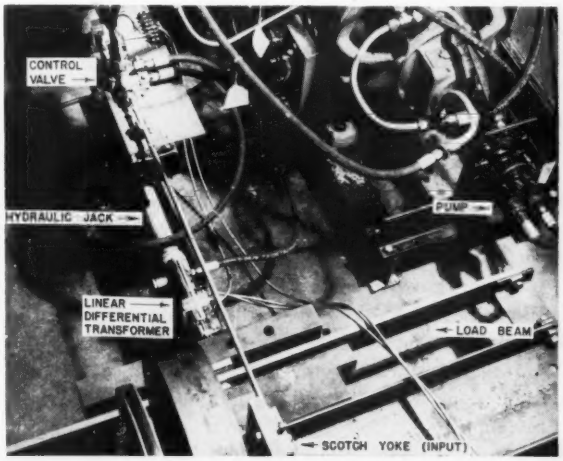

FIG. 16. Close-up view of dynamic simulator.

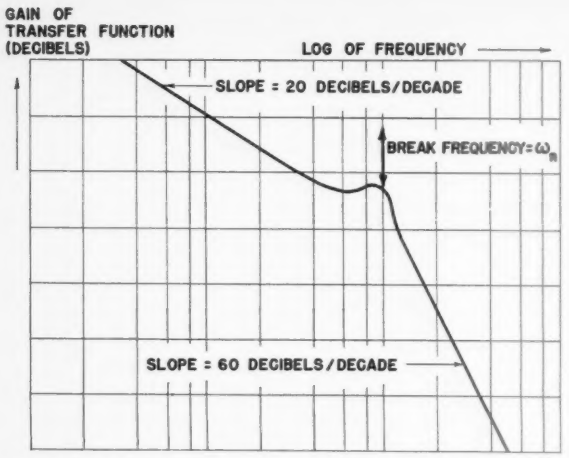

FIG. 17. Bode diagram of the hydraulic open-loop system resulting from the approximation, $q = k_1 x_v$.

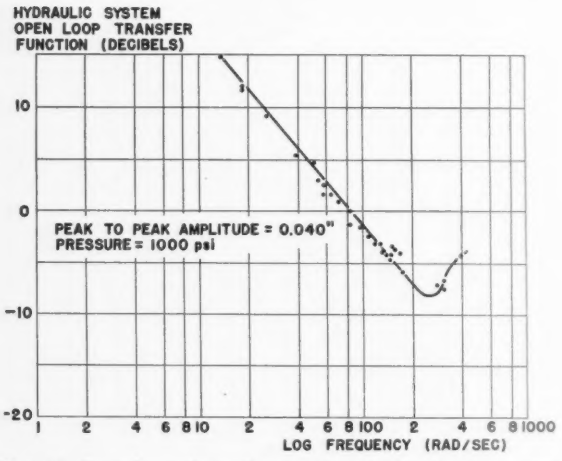

FIG. 18. Experimental data for the dynamic simulator open-loop transfer function.

db. line at $\omega = 1$, which is the velocity constant K_v. ζ determines the characteristics of the transfer function in the vicinity of the break frequency, but since f_c is unknown, little can be said about ζ except that it is of the order of 0.2.

If the experimental data have the same gain characteristics as that of the theoretical gain, then the theoretical open-loop transfer function of the hydraulic system is correct at least over the frequency and amplitude range tested. This statement assumes a minimum phase shift system. This assumption is borne out by the phase estimates made from the Brush recordings as they are minimum phase.

A plot of experimental gain-frequency data is shown in Fig. 18. It can be seen that the general form of the experimental data agrees with the general form of the theoretical results. Both have the same 20-db. per decade slope above the peak, and both have a peak. Unfortunately data were not taken sufficiently high in frequency to verify the 60-db. per decade slope above the break frequency. However, the phase data taken at the highest frequency indicate that this slope is present above the break frequency.

Examinations of the recorded data indicate that at a radian frequency of 13, the experimental phase shift of the transfer function x_c/x_v is about $-90°$. The nature of the Brush recordings precludes preciseness in phase measurements. However, this indication agrees very well with the theoretical value of $-90°$ at a frequency this far below the peak. At a radian frequency of 295 which occurs close to the peak, the experimental phase shift is about $-170°$. The theoretical phase shift of the transfer function at the break frequency is $-180°$. Although this evidence is not very accurate, it lends support to the validity of the theoretical transfer function that is based upon the assumption of flow proportional to valve displacement.

As further evidence, it is interesting to note the fair check afforded by numerically fitting the theoretical curve to the experimental curve utilizing as known parameters,

k_c = 1,735 lbs. per in.
a = 2.96 sq.in.
m_c = 0.226 lb. sec. per in.
k_1 = 240 in.^{2} per sec. (evaluated from static valve characteristics)
k_c is of the order of 10^4 lbs. per in.

The experimental value of ω_n is about 330 rad. per sec. Using this value, k_c may be calculated by means of Eq. (27a) and the known parameters. From this it is found that k_c = 22,800 lbs. per in., the right order of magnitude.

The experimental velocity constant of the system is 78 per sec. The theoretical velocity constant is given by

$$K_v = k_1 k_c / a m_c \omega_n^2 \qquad (28)$$

Using the experimental value of K_v and the calculated value of k_c in Eq. (28), k_1 may be determined. From this k_1 = 256 in.^{2} per sec. The value of k_1 determined from the static flow characteristics of the valve is about 240 in.^{2} per sec. It is felt that this is a fair check of the theoretical velocity constant.

On the basis of the experimental evidence, it can be concluded that the flow proportional to valve displacement assumption is a reasonable one at least over the frequency range measured. It is felt that this frequency region is significant due to the possibility of oscillations in the hydraulic servomechanism and airplane motion within this range. The hydraulic system has zero phase margin in the vicinity of 300 rad. per sec. If the loop were closed with unity feedback, there would be only about 4 db. of gain margin which is low for a stable system if the parameters are subject to much change.

STABILITY AND COMPENSATION OF THE CONTROL SYSTEM

It is appropriate at this time to consider the design of the hydraulic system from a general point of view

Essentially what is required in the logical design of the system? Clearly, the first step must involve the determination of the characteristics of the various mechanical and hydraulic components that are available. The preceding sections of this paper have discussed in some detail the problems associated with the determination of suitable linear approximations for the characteristics of the control valve and hydraulic jack with load. The second step in design must entail a determination of exactly what the hydraulic system is to do. Quantitative specifications must be determined to guide the design. The third step is the design of the system to meet these specifications, with the design procedure based on the analytical description realized in the initial step. The design is then completed with the experimental testing of the system and the adjustment of design parameters to compensate for the effects of incidental friction, etc.—phenomena that could not be conveniently considered in the original synthesis.

It is the purpose of this section to indicate generally the problems associated with the second step in the design mentioned above—the determination of specifications for the hydraulic system. Evidently, it is impossible to assign desired characteristics to the hydraulic system unless the role this system is to play in the overall airplane control system loop is determined. For example, the lag time permitted in the hydraulic system can be determined only by a consideration of the lags inherent in the rest of the control system and the total lag permitted for the overall system. But the lag allowable in the hydraulic system is of fundamental importance in the design, for the smaller the amount of lag permitted, the higher must be the gain of the hydraulic loop, and, accordingly, the greater will be the difficulties associated with stabilization of this hydraulic loop.

In another sense, the synthesis of the hydraulic system is stymied at once if no consideration is given to the rest of the overall aircraft control system. A principal point made previously was that the appropriate linear description of the hydraulic control valve depends on the frequency range of interest and the load characteristics. The frequency range of interest is determined by two factors—the stabilization problems of the hydraulic loop alone (i.e., the frequency band over which the system has sufficient gain to oscillate if the phase is correct), and the frequencies of importance in the design of the overall control system. Thus, the hydraulic system can be intelligently designed only if the characteristics of the overall control system are studied. Furthermore, any stabilization of the overall system will change the band of frequencies passed in the overall loop. Hence, not only must the characteristics of the aerodynamics and the mechanical components be considered, but, in addition, the general properties of any stabilization or compensation networks introduced in the overall control loop must be known.

Thus, if an attempt is made to design the hydraulic system without consideration of the overall control system, the designer is left in the position of not knowing exactly what is wanted or even what factors are of importance. The following paragraphs indicate briefly the basic characteristics of a simple overall control system of a hypothetical airplane and the general manner in which such a system might be stabilized and the performance characteristics controlled. From a development such as indicated below, an appropriate set of specifications for the hydraulic system stability, speed of response, and accuracy can be determined.

TABLE 1
Airplane Characteristics

Gross weight, W	13,700 lbs.
Wing area, S	270 sq.ft.
Aspect ratio, A.R.	5.0
Flight Mach Number	0.85
Flight altitude	10,000 ft.
Longitudinal derivatives and constants:	
$C_{T_0} + C_{L_\alpha}$	5.3
$2C_{L_0} + C_{L_u}$	0.3
C_{M_α}	−0.016
$C_{M_{\dot\theta}}$	−0.034
$C_{D_\alpha} - C_{L_0}$	0.16
C_{L_0}	0.069
$2C_{D_0} - C_{T_0} + C_{D_{u'}}$	0.55
C_{M_α}	−0.64
$(1/\tau^2)\, C_{M_{\ddot\theta}} - 2k'$	−0.12
$C_{M_{u'}}$	0.15
τ	0.97
C_{M_δ}	−0.63

TABLE 2
Assumed Parameters for Mechanical Part of Control System

Control column mass, m_b	4 slugs
Bob weight mass, m	2 slugs
Effective control linkage mass, m_p	0.2 slugs
Control linkage spring rate, k	10^4 lbs. per ft.
Control linkage damping factor, f_p	100 lb. sec. per ft.

Airplane and Stick Dynamics Transfer Functions

The pertinent physical characteristics and stability derivatives of the hypothetical airplane selected for analysis are given in Table 1. These values have been taken principally from reference 10. Based on these numbers and the longitudinal stability equations, the open-loop transfer function relating the vertical acceleration of the airplane to the displacement of the airplane elevator takes on the form,

$$\frac{NG}{\Delta_e} = \frac{Vs(A - \textcircled{H})}{\Delta_e} = \frac{150\ Vs(s + 0.28)}{(s^2 + 0.31s + 0.025)\ (s^2 + 7.1s + 63)} \tag{29}$$

Neglecting the phugoid, which is essentially of no interest in the problem at hand, the above transfer function can be reduced to

$$NG/\Delta_e = 150V/(s^2 + 7.1s + 63) \tag{30}$$

As stated previously, the constants associated with the control stick dynamics are subjected to some engineering revision. However, for the purposes of this example, typical values have been arbitrarily selected and are tabulated in Table 2. Using these values, the transfer function relating the input, x_p, into the hy-

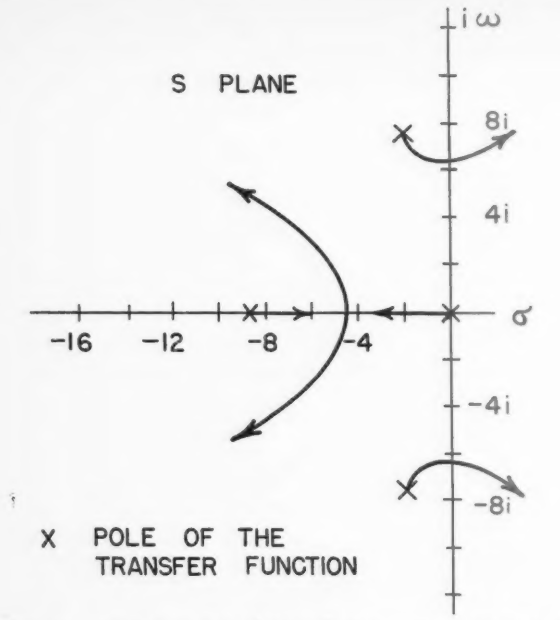

FIG. 19. Root locus plot of the overall uncompensated control system transfer function.

draulic loop, to the vertical acceleration, ng, acting on the bob weight, is given by

$$\frac{X_p}{NG} = \frac{-16{,}100}{s(s^3 + 500s^2 + 1.9 \times 10^4 s + 4 \times 10^5)} \tag{31}$$

At the frequencies that are of interest, this transfer function can be approximated with sufficient accuracy by,

$$X_p/NG = -0.33/s(s + 8.2) \tag{32}$$

Then, taking the transfer function of the hydraulic components to be unity, the open-loop transfer function for the overall system is simply the product of Eqs. (30) and (32), or

$$\text{constant}/s(s + 8.2)\ (s^2 + 7.1s + 63) \tag{33}$$

Stability of the Overall System

Following the method of Evans, the poles of the open-loop transfer function have been indicated in the complex frequency domain in Fig. 19. Note that there are poles at the origin and at $\sigma = -8.2$ arising from the stick characteristics and complex conjugate poles from the airplane dynamics. If the loop is now closed and the gain is increased from a very low value, the poles will move along paths as indicated in the figure, and at relatively low values of the gain the poles of the airplane dynamics move into the right-hand side of the frequency plane thereby indicating that the system has become unstable.

It is at once apparent that the system can be stabilized simply by maintaining the gain at a sufficiently low value. However, this is incompatible with the demand for rapid response, and, without being quantitative, it can be stated that stability attained simply by reduction of gain is becoming less and less acceptable on high-speed fighter airplanes.

Therefore, the basic question is: How can such a control system be stabilized with no severe penalty to the response rate? Several methods of compensation are under study, of which one will be discussed in the remaining paragraphs.

Compensation of the Overall Control System

In terms of the root locus plot alone, Fig. 19, the system can be compensated in any desirable manner. The basic problem is to effect this compensation in a manner that is mechanically feasible and as simple as possible. Thus, the problem of compensation can be stated as follows.

First, suitable specifications for this particular control system are chosen with regard to stability and rate of response. A transfer function is then chosen which yields these specified characteristics. This transfer function is then interpreted in terms of the existing components of the control system and additional components necessary to give the desired compensation.

The basic type of compensation that seems to be most effective theoretically is a lead form of network. A generalized form of transfer function for the desired compensation network would be of the form

$$\frac{s^2 + 2\zeta\omega_n s + \omega_n^2}{s^2 + as + b^2} \quad (\omega_n < b) \tag{34}$$

The authors of the present paper have devoted some time to the design of a mechanical and hydraulic system that will effect the above type of compensation. The most attractive possibility from the standpoint of reasonable design takes on the form of a twin-T system, as shown in Fig. 20, inserted in the control system at the input to the control valve. It is completely analogous to an electrical twin-T network and, indeed, is merely the expression of such a network in terms of mechanical and hydraulic components.

The effect of adding such compensation can then be described on an Evans plot in the complex frequency plane. The twin-T is tuned such that the zeros of the

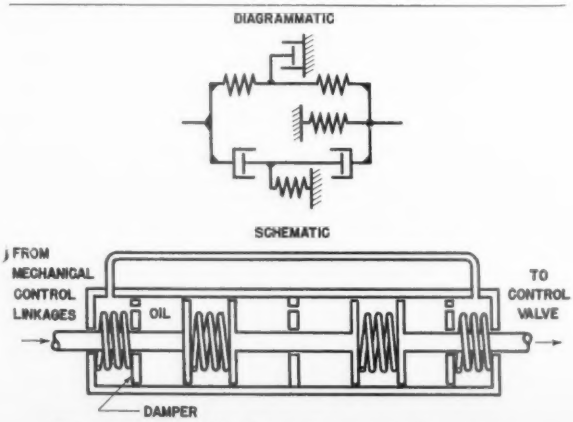

FIG. 20. Schematic of twin-T compensating system.

compensation transfer function lie as close as possible to the poles of the airplane dynamics transfer function *in their least stable position*. This effectively erases these poles from further consideration. Further, the twin-T is designed such that the poles introduced by the denominator of the compensation transfer function lie along the negative real axis at a distance removed from the origin. The resulting pole configuration is shown in Fig. 21.

If now the gain is increased, the poles move along loci as depicted in the figure, and it is seen that instability occurs because of the stick dynamics but at a much increased value of the gain. Accordingly, the overall system has been improved since the higher values of gain which can be realized will result in an increased response rate.

Conclusions

Analytical studies indicate that the inherent nonlinearity in the control valve of the control system can be approximated by a linearization in which the rate of fluid through the valve is taken proportional to its displacement. The range of variables over which the linearization is satisfactory depends in a quantitative manner upon the characteristics of the control system load. Further, the range of frequencies over which the linearization is valid is large enough to encompass the frequencies of interest in the design of the overall control system. The approximation is also substantiated by experimental data.

Specifications for the hydraulic components of the control system depend upon the characteristics of the remainder of the system including the dynamics of the airplane.

If both stability and rapid response are demanded of this type of control system, some type of compensation must be introduced which is tuned to the critical instability frequency. A mechanical-hydraulic method of compensation appears suitable for this purpose, but much work remains to be done on this phase of the problem.

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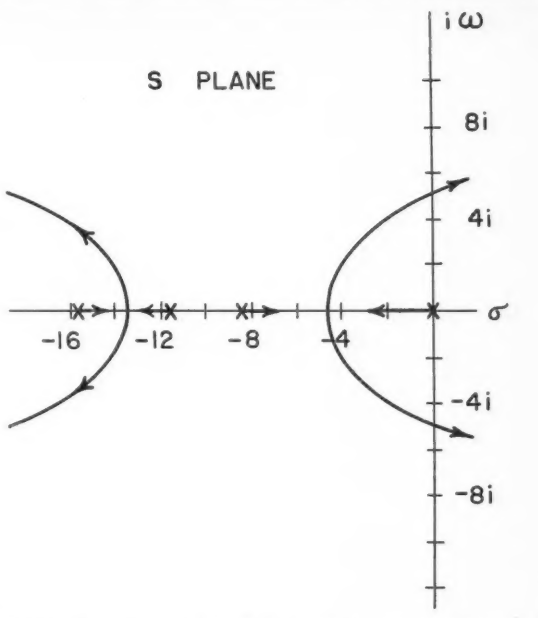

Fig. 21. Root locus plot of the overall compensated control system transfer function.

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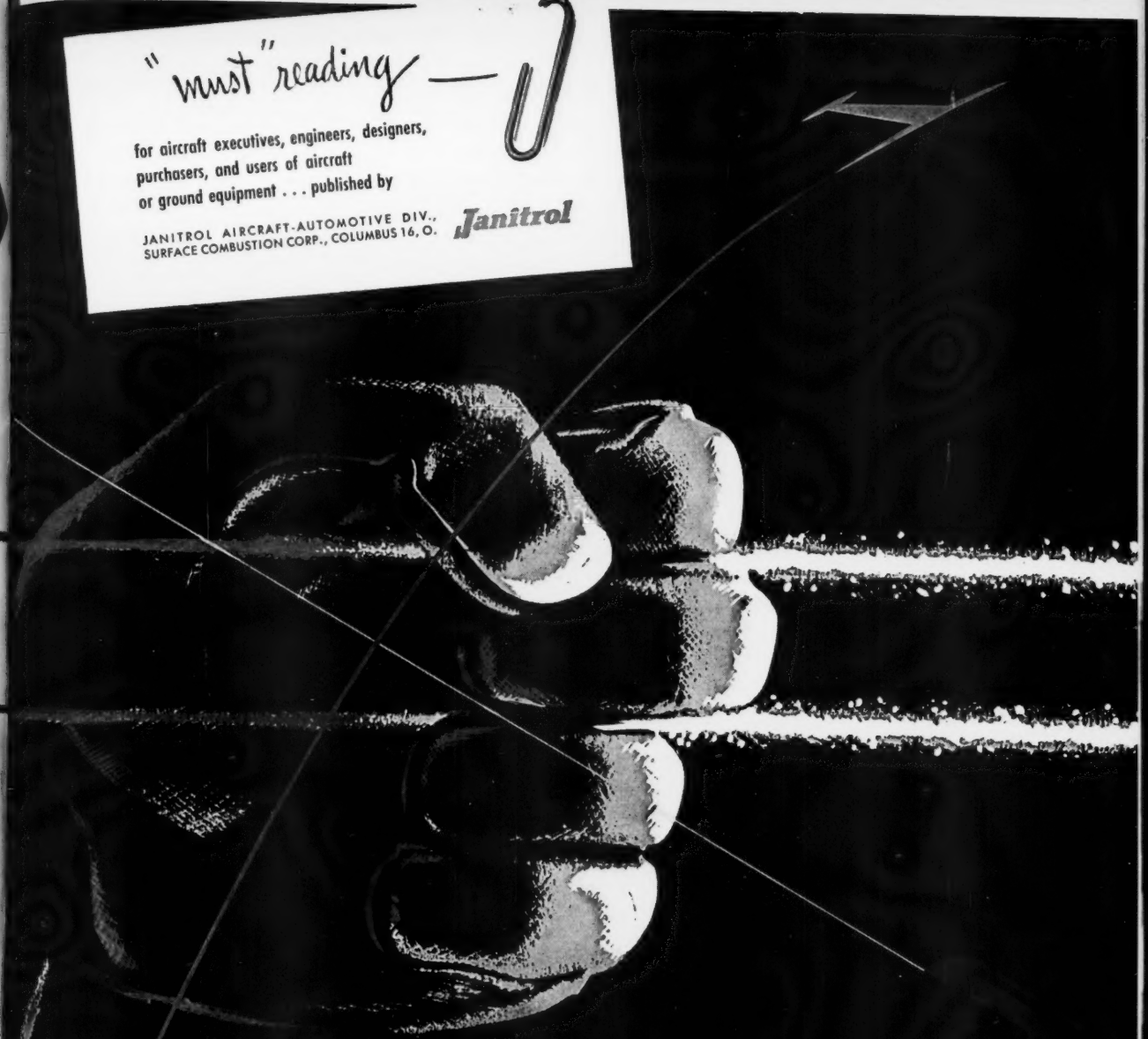

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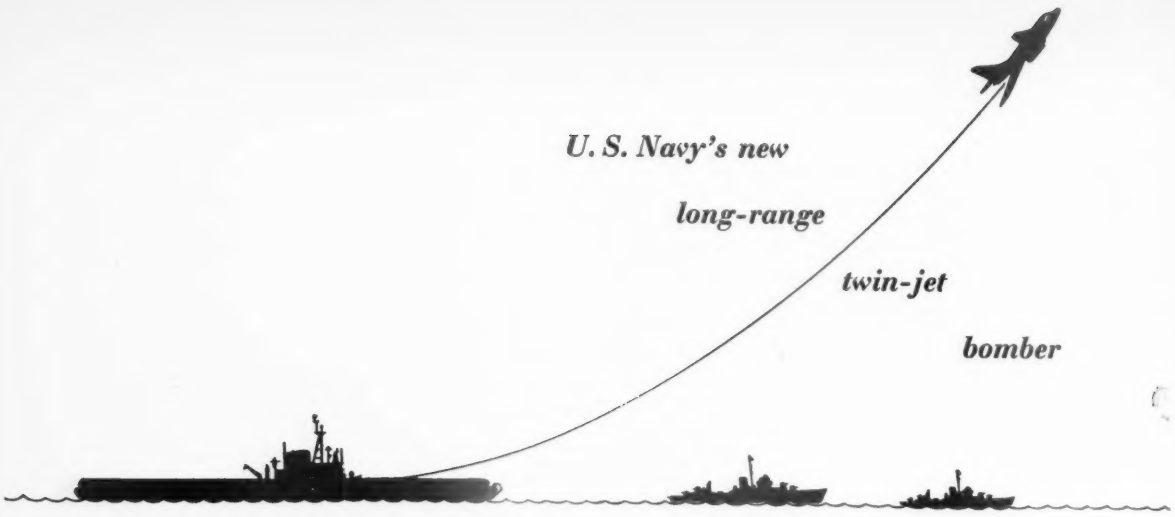

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eoretical Determination of the Minimum Drag of Airfoils at Supersonic Speeds

By

Robert T. Jones

Ames Aeronautical Laboratory, N.A.C.A.

Consider a thin wing in frictionless flow, and suppose the plan form of the wing and also the total lift to be given. The drag of the wing will then depend on the way in which the lift is distributed over its surface. In a previous paper, it was shown that the minimum drag occurs when the superposition of the induced disturbance fields in forward and reversed motion results in a constant value of the induced downwash at all points of the wing surface. Similar problems involving the ideal distribution of thickness over the surface were found to lead to similar conditions governing the distribution of pressure in the superimposed or "combined" flow field.

The present paper describes a method for determining mathematically the combined disturbance field and, in certain cases, the minimum drag of wings at supersonic speeds. The simplest analytic example is provided by the wing of elliptic plan form, which achieves its minimum drag when the lift is distributed uniformly over the surface. With a symmetrical distribution of thickness, the requirement of minimum drag for a given total volume is found to lead to profiles of constant curvature.

Preprint No. 375

Similarity Laws for Stressing Heated Wings

By

H. S. Tsien

California Institute of Technology

It will be shown that the differential equations for a heated plate with large temperature gradient and for a similar plate at constant temperature can be made the same by a proper modification of the thickness and the loading for the isothermal plate. This fact leads to the result that the stresses in the heated plate can be *calculated* from *measured* strains on the unheated plate by a series of relations called the similarity laws. The application of this analog theory to solid wings under aerodynamic heating is discussed in detail. The loading on the unheated analog wing is, however, complicated and involves the novel concept of feedback and "body force" loading. The problem of stressing a heated box wing structure can be solved by the same analog method and is briefly discussed.

Calculation of the Stability of the Laminar Boundary Layer in a Compressible Fluid on a Flat Plate with Heat Transfer

By

E. R. Van Driest

North American Aviation, Inc.

The amount of cooling required to stabilize completely the laminar boundary layer on a flat plate at supersonic speeds with zero pressure gradient is calculated using the Lees-Lin theory. It is found that, above about Mach Number 9, it is impossible to stabilize the layer with any amount of cooling when a Prandtl Number of 0.75 and the Sutherland viscosity-temperature law are assumed. The distribution of mean properties across the boundary layer is obtained by the Crocco method. The inviscid, as well as viscous, solutions are determined. Use of the stability results in missile aerodynamic-heating analysis is illustrated by means of V-2 flight-temperature data.

A Drag Reduction Method for Wings of Fixed Plan Form

By

E. W. Graham

Douglas Aircraft Company, Inc., Santa Monica Division

A method is given for reducing the drag of wings of fixed plan form, while maintaining constant some property such as wing lift or wing volume. This drag reduction is accomplished through adjustment of the wing twist and camber if lift is fixed or by adjustment of the thickness distribution if the volume is fixed. As an example, the drag due to lift of flat rectangular wings and flat delta wings is studied. For the rectangular wings, it was found that no drag reduction could be obtained with twist, while camber led to a drag reduction that was negligible for high effective aspect ratios and large for low effective aspect ratios. The camber was most effective near the wing tips. Twist was found to be useful in reducing the drag due to lift of delta wings. For delta wings with supersonic or sonic leading edges, a uniform camber (constant across the span) produced no improvement.

The interference drag for two superimposed pressure distributions comes from the pressures of one distribution acting on the local angles of attack for the other distribution. Two pressure distributions are called orthogonal if their interference drag is zero. The drag due to lift of any pressure distribution may be reduced by combining it with an orthogonal pressure distribution whose lift is not zero. This combined distribution can in turn be improved by a similar process. A procedure for constructing orthogonal distribution is given.

Equilibrium Temperature of an Unheated Icing Surface as a Function of Air Speed

By

Bernard L. Messinger

Lockheed Aircraft Corporation

The thermal analysis of a heated surface in icing conditions has been extensively treated in the literature. Except for the work of Tribus, however, little has been done on the analysis of an unheated icing surface. This latter analysis is significant in the design of cyclic thermal

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deicing systems that are attractive for small high-speed aircraft for which thermal anti-icing requirements have become severe.

In this paper, a complete analysis of the temperature of an unheated surface in icing conditions is presented for the several significant régimes (i.e., less than 32°F., at 32°F., and above 32°F.) as a function of air speed, altitude, ambient temperature, and liquid water content.

The results are presented in graphical form and permit the rapid determination of surface temperature for a wide range of variables. Curves are presented to determine the speeds beyond which no ice accretion will occur. Curves are also presented to indicate the surface temperature and the rate of ice sublimation which take place when an ice-covered surface emerges into clear air.

One significant result of this study is the introduction of a new basic variable referred to as the "freezing-fraction," which denotes the proportion of the impinging liquid which freezes in the impingement region. The fact that some of the liquid does not freeze in the impingement region tends to explain the observed variation in ice formation shape with temperature, speed, and water catch.

New test data obtained at Mt. Washington, N.H., for stagnation-point surface temperatures of an unheated plastic cylinder in natural and artificial icing conditions are included in an appendix. These data substantiate the validity of the assumptions made in the theoretical analysis.

Preprint No. 342

Boundary-Layer Stability and Transition in Subsonic and Supersonic Flow

By
Carl Gazley, Jr.
General Electric Company

Accurate prediction of the aerodynamic characteristics of a body at high flight speeds requires knowledge of the characteristics of the existing boundary layer. Although the effects of compressibility on the characteristics of both laminar and turbulent boundary layers are known rather well, little information has been available as to how the transition between the two types of flow is affected by compressibility and other factors. Even in subsonic flow, the effects of such variables as free-stream turbulence, surface curvature, pressure gradient, surface roughness, and surface temperature are known only qualitatively.

While the theory of laminar boundary-layer stability yields the conditions necessary for instability, it does not permit prediction of the transition point. This theory is, however, useful in indicating possible effects of the several variables on transition. It has recently been extended

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to compressible flows with heat transfer and with pressure gradient.

This paper presents the available data in subsonic and supersonic flow for the effects of free-stream turbulence, surface curvature, pressure gradient, surface roughness, surface temperature, and Mach Number on the transition position. New supersonic data are included from rocket flights, firing-range tests, and wind-tunnel tests. The effects of the several variables on transition are compared with the theoretically predicted effects on boundary-layer stability.

In general, the experimental data for transition confirm the trends indicated by the stability theory. Perhaps the most significant deviation from the trend expected from the stability theory is the relative insensitivity of supersonic transition to surface-temperature variation. The transition Reynolds Number range appears to increase with increasing Mach Number in both firing-range tests, where relatively low surface temperatures occur, and in wind-tunnel tests, where relatively high surface temperatures occur.

Blade Adjustment in Axial-Flow Compressor Stages

By

Allan W. McCoy and Alton V. Hooper

Sverdrup & Parcel, Inc.

An investigation of blade adjustment as a means of achieving volume regulation of an axial-flow compressor stage is presented. The effectiveness of such blade control is established and defined as the relative change of volume flow per unit of adjustment angle at constant pressure rise.

In the case of a grid element, the effectiveness of blade control is shown to be dependent upon the principal design parameters of reaction ratio, flow, and pressure coefficients. Low reaction ratios should be employed for stator-blade control, and, for corresponding use of rotor-blade adjustment, the preference is toward high reaction ratios.

Radial distribution of blade-control effectiveness is shown for several conventional stage types without consideration of radial equilibrium and nonuniform energy addition. In case of stator grid adjustment, the distribution of effectiveness indicates maximum values at the blade root section—i.e., with the adjustment for increase in flow, the axial velocities tend to rise rapidly at the hub. Rotor-blade control in these conventional stage diagrams affords a somewhat more uniform distribution of effectiveness. Special stage designs for uniform spanwise distribution of adjustment effectiveness are also discussed.

Analysis of Stiffened Curved Panels Under Shear and Compression

By

M. A. Melcon and A. F. Ensrud

Lockheed Aircraft Corporation

This paper presents a method of analysis for curved panels reinforced by longitudinal stiffeners subjected to shear and compression. New formulas have been derived for the critical buckling stress of curved panels in shear and for the various effects of the diagonal tension field in the postbuckling state of the sheet. These latter effects are expressed by fictitious compressive stresses in the stiffeners which are then combined by an interaction equation with the compression stresses due to the external loading. In addition, a formula is given for the ultimate shear strength of the sheet. The method proposed in this paper has been compared with available experimental data, and satisfactory agreement is found. The method has been put in a form that requires the solution of certain mathematical relations and a minimum of chart reading and, hence, is readily adaptable to IBM or other high-speed computing techniques. A sample interaction diagram is included showing how the results of this method may be presented for practical application.

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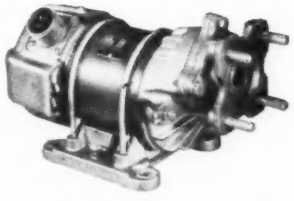

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News of I.A.S. Members

(*Continued from page 19*)

Harrison C. Chandler, Jr. (M.), Sales Engineer for Airplane Fuel Cells, Defense Products Division, The Firestone Tire & Rubber Company. Formerly, Development Engineer, Firestone.

Dr. Chieh-Chien Chang (M.), Mathematics Department, The University, Manchester, England. Formerly, Associate Professor of Aeronautics, Department of Aeronautics, The Johns Hopkins University.

James V. Crawford (M.), Assistant Chief Engineer in Charge of Heat Transfer and Cabin Pressure Department, AiResearch Manufacturing Company, Division of The Garrett Corporation. Formerly, Administrative Engineer, AiResearch.

Handel Davies (A.F.), Chief Superintendent, Aeroplane and Armament Experimental Establishment, Ministry of Supply, Boscombe Down, England. Formerly, Head, Aero Flight Section, Royal Aircraft Establishment, England.

Captain Joseph E. Dodson, U.S.N. (M.), Navy Member, Aircraft Production Resources Agency, Wright-Patterson A.F.B., Ohio. Formerly, Fiscal Director, Bureau of Aeronautics, Department of the Navy, Washington, D.C.

Emery E. Eckert (T.M.), Junior Engineer "B," Boeing Airplane Company. Formerly, Student, Cal-Aero Technical Institute.

Professor Vernon K. Gunkel (M.), Aeronautics Department, Navy Postgraduate School, Monterey, Calif. Formerly, Chief, Mechanical Section, Engineering Branch, Industrial Group, Ordnance Guided Missile Center, Redstone Arsenal, Ala.

Richard C. Henshaw (A.F.), Manager of Engineering, Lord Manufacturing Company. Formerly, Manager, Production and Sales Engineering, Lord.

Theodore Hoffman (T.M.), Customer Service Representative, Missile Service Group, Douglas Aircraft Company, Inc. Formerly, Airman 2/C, U.S.A.F., Senior Draftsman, Langley Air Force Base, Va.

Ray Jensen (M.), Senior Project Engineer, Heat Transfer and Cabin Pressure Department, AiResearch Manufacturing Company, Division of The Garrett Corporation. Formerly, Project Engineer, Accessory Valves and Heat Transfer, AiResearch.

John W. Lawton (M.), Service Supervisor, Central Area, Aviation Gas Turbine Division, Westinghouse Electric Corporation. Formerly, Service Engineer, Westinghouse Office, McDonnell Aircraft Corporation.

Joseph T. Minarovich (T.M.), Analytical Design Engineer, Hamilton Standard Division, United Aircraft Corporation. Formerly, Hamilton Standard Fellow, The Pennsylvania State College.

Wilbur S. Mount (M.), Manager, Aviation Department, Socony-Vacuum Oil Company, Inc. Formerly, Manager, Product Engineering Division, Gasoline and Fuel Oil Department, Socony-Vacuum.

Lester W. Musser, Jr. (T.M.), now Senior Engineering Draftsman, Goodyear Aircraft Corporation.

Richard T. Nalle, Jr. (M.), Manager of Production, Aviation Gas Turbine Division, Westinghouse Electric Corporation. Formerly, Assistant to the Division Manager, A.G.T.D., Westinghouse.

Derry D. Noisom (T.M.), Technical Staff Engineer, Hughes Aircraft Company. Formerly, Lieutenant, Guided Missile Officer, 1st Guided Missile Group, U.S. Army, Fort Bliss, Tex.

John F. M. Oram (M.), "Britannia" Flight Research Engineer, Bristol Aeroplane Company, England. Formerly, Technical Expediter, Guided Missiles, Bristol.

Richard H. Parvin (M.), Contract Administrator—Electronics, Engineering and Research Corporation. Formerly, Project Engineer, Twin-Engine Instrument Flight Trainer, Engineering and Research Corporation.

William J. Pattison (M.), Director of Sales and Service, AiResearch Manufacturing Company, Division of The Garrett Corporation. Formerly, Assistant to the President, AiResearch.

Awarded D.F.C.

Colonel Roscoe Turner (M.), President, Roscoe Turner Aeronautical Corporation and Lake Central Airlines, Inc., became the first civilian airman since 1932 to receive the Distinguished Flying Cross. The award was presented to him by Gen. Nathan F. Twining, Acting Chief of Staff, U.S.A.F., in a ceremony at the Pentagon Building on August 14. This decoration, made possible by a special act of the 82nd Congress, was given in recognition of Colonel Turner's "meritorious achievements and contributions toward the advancement of the science in aerial flight."

Alan Pope (M.), Supervisor, Experimental Aerodynamics Division, The Sandia Corporation. Formerly, Supervisor, Wind Tunnel Section, Sandia.

Perry W. Pratt (M.), Chief Engineer, Pratt & Whitney Aircraft Division, United Aircraft Corporation. Formerly, Assistant Chief Engineer, Pratt & Whitney.

Guido E. Ransleben, Jr. (T.M.), Research Engineer "B," Aeroelasticity Section, Department of Engineering Mechanics, Southwest Research Institute. Formerly, with Reynolds Andricks, Consulting Engineers.

Harold J. Roed (T.M.), Methods Engineer, Minneapolis-Honeywell Regulator Company. Formerly, Design Draftsman, Airplane Division, McDonnell Aircraft Corporation.

Major Ned Schramm, Jr., U.S.A.F. (T.M.), now Assistant Director of Procurement, Box P, Hq., 20th Air Force, c/o Postmaster, San Francisco, Calif.

Colonel Harry G. Spillinger, U.S.A.F. (A.F.), Deputy Director of Accounting, Headquarters, U.S.A.F., Washington, D.C. Formerly, Comptroller, Air Force Missile Test Center, Patrick Air Force Base, Fla.

Alan H. Stenning (T.M.), Research Engineer, Dynamic Analysis and Control Laboratories, Massachusetts Institute of Technology. Formerly, Research Assistant, Gas Turbine Laboratory, M.I.T.

William E. Stinson (A.F.), Vice-President, Humphrey & Vandervoort, Inc., Tonawanda, N.Y. Formerly, Chief of Preliminary Design, Bell Aircraft Corporation.

Pauline V. Teague, nee Glazier (T.M.), Research Engineer, Northrop Aircraft, Inc., Cocoa, Fla. Formerly, Research Engineer, Northrop, Hawthorne, Calif.

Bernard Towler (T.M.), Commercial Pilot/Engineer, Spartan Air Services Limited, Canada. Formerly, Design Draftsman/Commercial Pilot, A. V. Roe Canada Limited.

Lieutenant Colonel Albert J. Wetzel, U.S.A.F. (M.), Pilot and Assistant to the Director of Guided Missiles, Office of the Secretary of Defense, Department of Defense, Washington, D.C. Formerly, Major, Pilot and Weapons Development Engineer, Hq., Armed Forces Special Weapons Project, Washington, D.C.

George S. Whitman (M.), Design Engineer "B," Lockheed Aircraft Corporation. Formerly, Administrative Engineer, Aircraft Armaments, Inc.

Thomas B. Woersching (T.M.), Chief Aerodynamicist, Goodyear Aircraft Corporation. Formerly, Design Development Engineer, The Glenn L. Martin Company.

First Lieutenant Edward D. Wong, U.S.A.F. (T.M.), Student Officer (Graduate), Institute of Technology, Wright-Patterson A.F.B., Ohio. Formerly, with Wright Air Development Center, Wright-Patterson.

Necrology

Colonel Halsey Dunwoody

Colonel Halsey Dunwoody, U.S.A. (Ret.), an I.A.S. Founder Member, died on September 2 in the Tompkins County Memorial Hospital, Ithaca, N.Y., of a stomach cancer. He was 71 years old.

Graduated from the United States Military Academy in 1905, Colonel Dunwoody received a B.S. degree from George Washington University in 1907 and an M.S. degree from Cornell University in 1915. He was appointed to the U.S.M.A. faculty in 1913 and in time became Director of the Department of Mechanical Engineering.

In 1917, Colonel Dunwoody, as a member of the American Expeditionary Force, was sent to France, where he learned to fly. During this period, he served with the Air Section of the U.S. Army Signal Corps as Chief of the Technical Department, Chief of Supply, Chief Purchasing Officer and Liaison Officer with the Allied Governments, and Assistant Chief of the Air Section. He was awarded the Distinguished Service Medal, the French Legion of Honor, and the Order of the Crown of Italy. After the war, he served as American representative of the Inter-Allied Aviation Commission and a member of the American Aviation Commission.

Retiring from the Army in 1919, Colonel Dunwoody held various civilian posts. These included those as Vice-President of Financial Trading Corporation, Vice-President and Sales Manager of Gardner Motor Company, Executive Vice-President of Universal Aviation Corporation, Vice-President of American Airways, Inc., and Vice-President of Rhodes, Perry, Martin, Inc. In late years, he served as a Transportation Consultant in the Pentagon.

Colonel Dunwoody was a past-officer of the Aeronautical Chamber of Commerce of America, Inc.

David M. Geeslin

David Martin Geeslin, M.I.A.S., suffered a heart attack and died in his office on August 4. He was 58 years old.

A native of Sumner County, Kan., Mr. Geeslin attended the Kansas State College from 1914 to 1916 and from 1919 to 1922. In 1922, he was graduated from Kansas State with a Bachelor of Science degree in Electrical Engineering.

Mr. Geeslin was employed between the years 1922 and 1938 by Westinghouse Electric and Manufacturing Company, first, as a Sales Engineer and, later, as a Service Engineer assisting in the erection of steam-turbine generating units. In 1939 and 1940, he was Assistant Electrical Engineer on the construction of small diesel-engine generating plants and transmission lines for the U.S. Department of Interior's National Park Board. He joined Cessna Aircraft Company in 1940 as a Structures Engineer and some time later became associated with the Civil Aeronautics Administration as an Aeronautical Engineer. He was serving in this latter capacity in the Los Angeles office of the C.A.A. at the time of his death.

He is survived by his widow.

Herbert H. Hoover

Herbert H. Hoover, N.A.C.A.'s Chief Test Pilot at the Langley Aeronautical Laboratory, Langley A.F.B., Va., and the recipient of The Octave Chanute Award for 1948, was killed on August 14 in an unsuccessful bail-out from a B-45 jet bomber that exploded at 10,000 ft. over Burrowsville, Va., during a research flight. Mr. Hoover, who was piloting, disengaged himself from the ejection seat. However, for some unknown reason, he was unable to pull the ripcord, and the parachute, which was not defective, did not open. His copilot, John A. Harper, parachuted successfully.

The 40-year-old pilot was graduated from the University of Tennessee in 1934 with a degree in Mechanical Engineering. He learned to fly with the U.S. Army Air Corps and, after completing a tour of active duty, signed up with Standard Oil Company as a pilot in South America. Late in 1940, he joined the staff at the Langley Aeronautical Laboratory.

Mr. Hoover achieved fame when, on March 10, 1948, he became the second pilot to fly faster than sound and the first civilian pilot to take the Bell X-1 through the "sonic barrier." He was also known for being one of the first pilots to fly through thunderstorms and hurricanes for scientific investigation.

For his contributions to supersonic flight research, Mr. Hoover received the Chanute Award in 1948 from the I.A.S., a trophy from the Air Force Association in 1948, and the Air Medal in 1950 at the direction of the President of the United States.

Stanwood W. Sparrow

Stanwood Willston Sparrow, M.I.A.S., died on August 14 in the Harrington Memorial Hospital, Southbridge, Mass., from injuries received when his automobile collided with a truck on Route 20.

Mr. Sparrow, who was born in Middleboro, Mass., on November 18, 1888, attended the local public school system and in 1911 was graduated from Worcester Polytechnic Institute with a B.S. degree in Mechanical Engineering. He was awarded an Honorary Doctor of Engineering degree in 1949.

From 1911 to 1918, Mr. Sparrow was employed by Stevens-Duryea Metz Company and by Robert T. Pollock Company for experimental work and drafting. In 1918, he joined the National Bureau of Standards in Washington, D.C., and was placed in charge of the altitude laboratory. A few years prior to his resignation in 1926 from N.B.S., he was made Chief of the Automotive Power Plant Section.

Mr. Sparrow's association with Studebaker Corporation, of which he was Vice-President in charge of Engineering at the time of his death, began in 1926. Initially, he was put in charge of engine development, but some time later he was made responsible for the Research Department. In 1941, he was transferred to Studebaker's Aviation Division as Supervisor of production tests and engineering work in connection with the production of the Wright Cyclone engine.

In addition to his I.A.S. membership, Mr. Sparrow belonged to the American Association for the Advancement of Science, American Society of Mechanical Engineers, American Society for Testing Materials, and Society of Automotive Engineers.

Emmett C. Teague

Lieutenant (j.g.) Emmett Clyde Teague, U.S.N.R. (inactive), T.M.I.-A.S., was killed on July 12 when the SNJ-2 he was piloting crashed into the Pacific Ocean near Seal Beach, Calif. Mr. Teague was a member of a Naval Reserve Organized Squadron.

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Born in Yoakum, Tex., on August 13, 1925, Mr. Teague attended the Galena Park (Texas) High School from 1938 to 1942. He enrolled in September of 1942 as a freshman at the Agricultural and Mechanical College of Texas but the following July discontinued his studies. He returned to Texas A. & M. in September of 1947 to complete his course and was graduated in January of 1950 with a B.S. degree in Aeronautical Engineering.

Immediately after his college graduation, Mr. Teague went to work for Douglas Aircraft Company, Inc., as an Engineering Draftsman in the El Segundo Plant. At the time of his death, he was a Designer at El Segundo.

Mr. Teague is survived by his wife, Mrs. Patricia Morgan Teague.

Stanley A. Vye

Word was received recently concerning the death of Stanley Allen Vye, M.I.A.S., on November 8, 1951. Further particulars were not given.

Mr. Vye was born in St. Cloud, Minn., on October 4, 1903. He attended high school in Minneapolis and later enrolled as a student at the University of Minnesota. He was graduated from Minnesota in 1933 with a Bachelor's degree in Aeronautical Engineering.

Immediately after being graduated, Mr. Vye obtained employment with Northwest Airways as Traffic Representative. In January of the following year, he joined Northrop Corporation as a Mechanic in the final assembly of wing and control surfaces. In November, 1935, he performed in a similar capacity for Consolidated Aircraft Corporation. The following January, he returned to Northrop as a Mechanic in the Control Surface Department and in 1936 was promoted to the position of Stress Analyst. At the time of his death, he was a Stress Engineer for the El Segundo Plant of Douglas Aircraft Company, Inc.

Mr. Vye is survived by his widow.

Raycroft Walsh

Raycroft Walsh, I.A.S. Associate Member and Founder Member, died on August 19 after a brief illness. His age was 63.

Mr. Walsh, who was a native of Boston, Mass., attended the Massachusetts Institute of Technology in 1908–1909 and Columbia University in 1909–1910. He was commissioned a Second Lieutenant, U.S.A., in 1910 and during World War I was assigned to the Aviation Section of the Signal Corps. He received flight instruction at Kelly Field, Tex., and Rockwell Field, Calif., and was subsequently stationed at France Field, Canal Zone, as Commanding Officer. In 1925, he was appointed Fiscal Officer in the Army Air Corps and the following year resigned his commission as Major to enter private industry. In 1932, he was appointed a Lieutenant Colonel in the Air Reserve.

Mr. Walsh was employed between 1926 and 1930 by McGraw-Hill Publishing Company and Cheney Brothers. In the latter year, he was named Vice-President and Director of Hamilton Standard Propeller Company, a Division of United Aircraft and Transport Corporation (now Hamilton Standard Division of United Aircraft Corporation). He became an official of the now-defunct United Aircraft Manufacturing Corporation in 1935. The following year, he was elected a Vice-President and Director of United Aircraft Corporation and 6 years later was made Senior Vice-President. He was named Vice-Chairman of the corporation in 1943, the position that he held at the time of his death.

Mr. Walsh is survived by his wife, Emma L. Walsh, a son, and two daughters.

Corporate Member News

• **Aluminum Company of America . . .** As soon as the necessary land can be purchased and government approvals obtained, Alcoa is planning to undertake the construction of a $400,000,000 aluminum smelting facility in the Taiya Valley district, near Skagway, Alaska. It is estimated that the Taiya development would require about 4 years for completion.

• **American Airlines, Inc. . . .** September 8 marked the tenth anniversary of the inauguration of American's air service to Mexico.

• **Bell Aircraft Corporation and Curtiss-Wright Corporation . . .** The Bell X-2 was returned to Bell's Buffalo, N.Y., plant to permit the installation of the 8,000-lb.-thrust Curtiss-Wright XLR-25-CW-1 rocket engine. The X-2 completed its powerless flight tests at the Air Force Flight Test Center, Edwards A.F.B., Calif., prior to being shipped back to Buffalo. The new power plant differs from previous rocket power plants in that it can be throttled like a jet engine to develop intermediate power ratings. After the engine is installed and the subsequent ground test work is completed, the X-2 will be returned to Edwards for the powered flight test program, presumably late this year or early next year.

• **Boeing Airplane Company . . .** William M. Allen, Boeing President, announced on last August 30 that "The Boeing Company has, for some time been engaged in a company-financed project which will enable it to demonstrate a prototype jet airplane of new design to the Armed Services and the commercial airlines in the summer of 1954."

• **The Bristol Aeroplane Company of Canada Ltd. . . .** The Bristol Britannia 175 transport, powered with four turboprop engines, made a successful maiden flight from Filton Airport, England, on August 16.

• **Cessna Aircraft Company . . .** The Helicopter Division is working on a long-range program for the U.S. Navy which involves design studies, experimental construction, and flight testing. . . . F. A. Boettger was elected Vice-President—Finance and Treasurer of the company at a recent meeting of the Board of Directors.

• **Consolidated Vultee Aircraft Corporation . . .** A new version of the Convair-Liner 340, designated the Convertible, offers a 27 per cent increase in seating capacity through provisions for quick rearrangement of the cabin interior. These provisions, seat track and movable bulkheads, make it possible to convert the aircraft to a high-density configuration of 56 seats. Structurally, the Convertible is the same as other Convair 340's, except that an additional window has been added on both sides forward of the propeller plane. Maximum gross take-off weight remains at 47,000 lbs.

• **Curtiss-Wright Corporation . . .** A new turboprop engine that is expected to dwarf in power any aircraft engine yet made public and an advanced series of propellers that "will pave the way for the eventual attainment of speeds up to 1,000 m.p.h." were recently announced. The engine in question is now in an advanced state of development at the Wright Aeronautical Division. The propellers, designated the Turboelectric series, are being produced at the Propeller Division and, it is said, are capable of harnessing power outputs up to 20,000 hp. and more. Included in the Turboelectric series are models designed for use with each of the high-powered military turboprop engines currently slated for production in the U.S., including Curtiss-Wright's new turboprop, Allison's T-38 and T-40, and Pratt & Whitney's T-34. Some models of Curtiss-Wright's extruded turboprop propellers range up to 20 ft. in diameter. They are of the three- and four-bladed single-rotation type and of the six- and eight-bladed dual-rotation type.

• **Douglas Aircraft Company, Inc. . . .** According to reports, Douglas is planning to continue with the development and production of its DC-8 jet transport,

. . . and on the new Mainliner Convairs, too, it's Pesco Pressurized Power and Controlled Flow!

United Air Lines' new, trim, sleek Mainliner Convairs, designed to provide radically improved service on short and medium-range trips, embody the latest and finest developments in aircraft efficiency and dependability.

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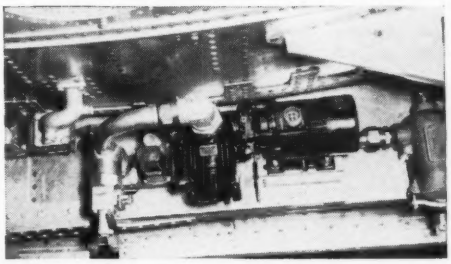
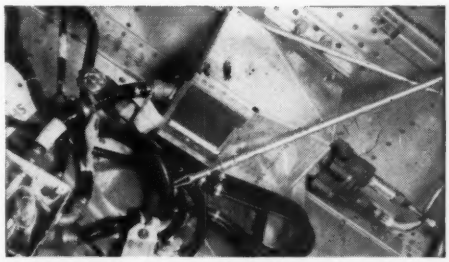
Precision-made, time-tested Pesco fuel pumps are only one of several Pesco products, including main and emergency hydraulic pumps, propeller feathering pumps, and cabin supercharger pump, specified by United Airlines as standard equipment on their new fleet of Mainliner Convairs. For complete information on these or other products, write or call today.



View shows the Pesco motor-driven fuel pump as mounted in the nacelle of a new Mainliner Convair.



Another Pesco product that is standard equipment on the new Mainliner Convair is this auxiliary hydraulic pump, located in the nose wheel of the plane.

engineering Pesco production
PRODUCTS DIVISION

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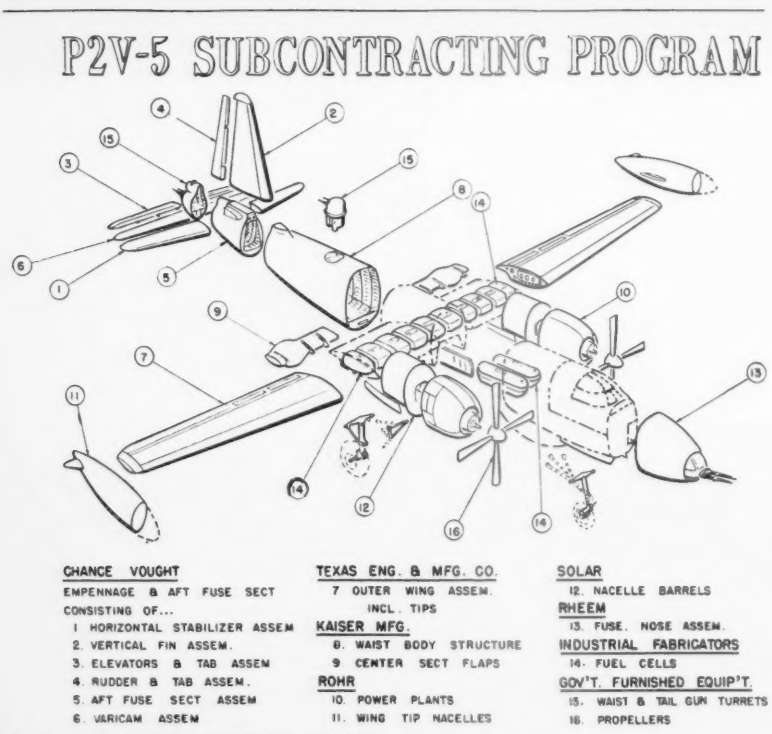


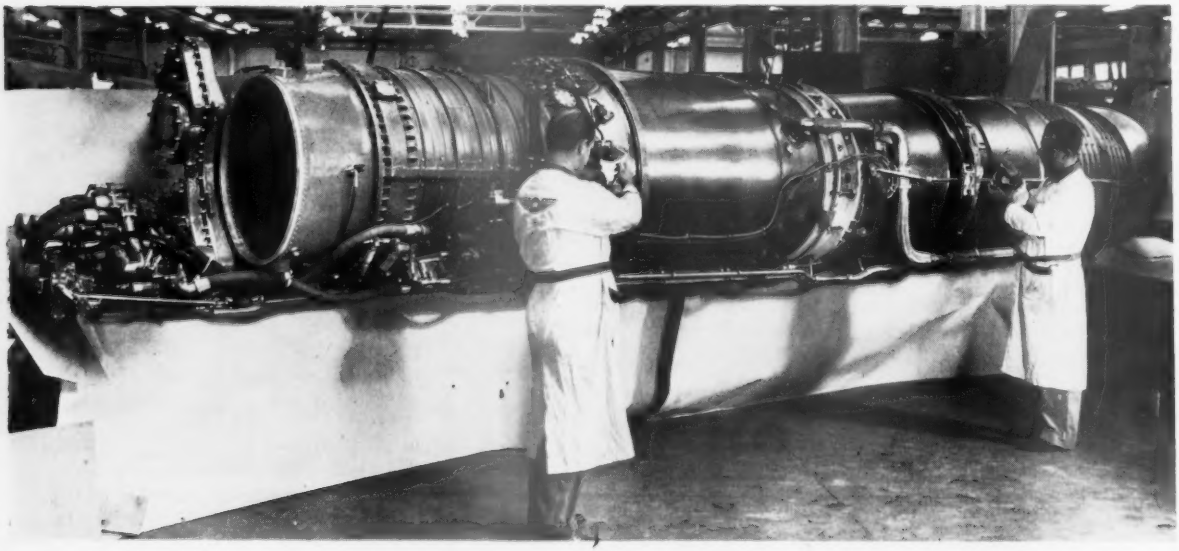
P2V-5 SUBCONTRACTING PROGRAM

An exploded drawing of the P2V-5 antisubmarine bomber, built by Lockheed Aircraft Corporation for the U.S. Navy, England, and Australia, shows the parts subcontracted to other suppliers. Dotted lines indicate key forward fuselage and center sections built by Lockheed; other sections, including Government-furnished items, are built or assembled in different parts of the country and shipped to Lockheed's Burbank plants. Government-furnished items include such equipment as propellers, engines, turrets, and armament. The landing gear is a purhcased item, not subcontracted.

without Government financing. It is said that the DC-8 will be powered by four Pratt & Whitney J-57 Turbo-Wasp jet engines and will accommodate between 70 and 120 passengers. A mock-up of the jet transport has already been completed. . . . The first of the Douglas C-118A Liftmaster transports was delivered recently to the U.S.A.F. for service with the Atlantic Division of Military Air Transport Service.

• **Fairchild Camera and Instrument Corporation . . .** The existence of the Fairchild-developed aerial camera, designated the CAX-12, was recently revealed by the U. S. Navy. This camera, which weighs only about 15 lbs. and is now in quantity production, was designed with high-speed film movements. It can be operated at ground speeds from 175 knots to near-sonic speeds and at altitudes varying from very low to very high. The CAX-12 uses 70-mm. film with sprocket holes along both sides. The removal magazines hold 100 ft. of film, the negatives of which are $2^1/_4$ in. square.

• **Fairchild Engine and Airplane Corporation. . .** An agreement between the Royal Dutch Aircraft Factories Fokker and Fairchild Engine and Airplane Corporation gives the Fairchild Aircraft Division the right to "handle the sales organization in the United States of all Fokker aircraft." It also gives Fairchild the option on all manufacturing rights in this country for Fokker models—i.e., the S-11 and S-12 primary trainers, the S-13 crew trainer, the S-14 jet trainer, and the twin-engined turboprop F-27 feeder transport. "Technical cooperation" will be conducted by both companies during the development of the F-27, called the "Friendship" as a



THE J-40 QUALIFIES FOR PRODUCTION

The new J-40 jet engine, now in production at Westinghouse Electric Corporation's Aviation Gas Turbine Division, was acclaimed in a recent U.S. Navy-Westinghouse announcement as "the world's most powerful qualified turbojet aircraft engine." Designed by Westinghouse engineers under the guidance of the Navy's Bureau of Aeronautics, the new engine is nearly 25 ft. long and about 40 in. in diameter. The J-40, it is said, is the first jet engine in the world to provide constant speed drive for airplane accessories as an integral part of the engine. Several new Navy fighter planes, including the McDonnell F3H Demon and Douglas F4D Skyray, are expected to be powered by the J-40. The JP-4 fuel was used in the J-40 throughout the Department of Defense's 150-hour qualification test.

COMFORT

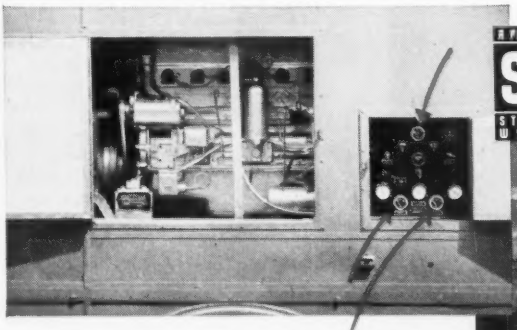
on the line!

NEW mobile aircraft air conditioner by Airtemp brings complete all-weather comfort to airliners with South Wind heaters

Complete on-the-ground, all-weather comfort for airline passengers is achieved by this new mobile air conditioner by the Airtemp Construction Corporation.

Airtemp chose Stewart-Warner South Wind Heaters, acknowledged leaders in the field of aircraft heating, for dependable cold weather operation. The heater supplies up to 200,000 BTU's—more than ample, even for arctic operation—direct to the plane's own ventilation system. Stewart-Warner supplies the electric fuel pumps and instruments, as well.

Already chosen by Chicago and Southern Air Lines, United Air Lines and Capital Airlines, the unit is finding ready acceptance by the industry for its dependability and ease of operation. Another example of South Wind leadership.



Left hand panel of truck with engine door open for inspection or service. Drive is direct to compressor. The instrument panel on the right carries Stewart-Warner liquid level and temperature gauges.

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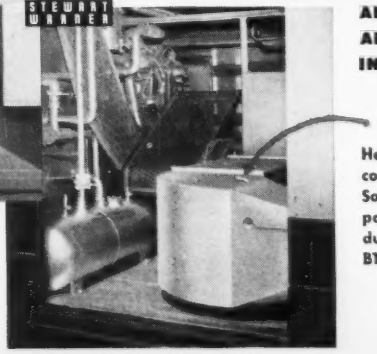


Heater installation. Only the damper control of the heater is visible. The South Wind heater itself is so compact that it fits completely inside the duct, yet supplies up to 200,000 BTU's of heat to cabin and cockpit.

28-passenger plane and the "Freightship" as an all-cargo aircraft. Fairchild Engine and Airplane Corporation has agreed to transfer, "as far as practicable," the European sales, repair, and service rights for its products to Fokker.

• **Fairchild Engine and Airplane Corporation, Fairchild Aircraft Division . . .** The C-119H completed Phase II of its flight test program at Edwards A.F.B., Calif., last August. . . . The first consignment of C-119 transports built for a foreign country were delivered to the Royal Canadian Air Force on August 27.

• **Fairchild Engine and Airplane Corporation, Fairchild Guided Missiles Division. . .** T. D. (George) Ellison has been named Comptroller of the Guided Missiles Division.

• **Fairchild Engine and Airplane Corporation, Stratos Division . . .** An agreement has been signed whereby Inter-Technique, S.A.R.L., of Paris, France, has been granted the exclusive sales rights for Stratos products in all European countries except Switzerland. These products include air-cycle refrigeration packages for both military and commercial aircraft, aircraft cabin superchargers, air-turbine drives, etc. Equipment sold by Inter-Technique will be manufactured at the Stratos plant in Bay Shore, L.I., N.Y.

• **Fletcher Aviation Corporation . . .** What is believed to be the first granting of manufacturing rights by a U.S. aircraft company to Japan since the signing of the recent peace treaty was accomplished recently by Fletcher. Under the terms of the agreement, Fletcher has licensed a Japanese company to manufacture its single-engined trainer.

• **General Electric Company . . .** Delivery of production armament systems for the Boeing B-47 bomber began in the latter part of August or approximately 14 months after the production contract was received by G-E from the Air Force. . . . A North American F-86D on loan from the U.S.A.F. has been assigned to G-E's Flight Test Group at Edwards A.F.B., Calif. It will be used for the development of the turbojet engine and its electronic control. . . . A new 9-in. welding electrode comparator slide rule that permits a comparison of G-E welding electrodes with those of other electrode manufacturers is available at G-E Welding Distributors. It is designated GEN-37B. . . . A new 49-page pocket-size booklet that describes the application, chemical analysis, and mechanical properties of G-E welding electrodes is now available from G-E Welding Distributors. The booklet is designated as GED-1634.

• **The B. F. Goodrich Company . . .** A new rubber lifeboat that is said to inflate itself within 30 sec. and to provide a 70° protection for 15 survivors in either subzero or tropical weather has been developed by Goodrich and the U.S. Navy's Small Craft Section of the Bureau of Ships. Deflated, the craft is about the size of a small steamer trunk; inflated, it measures 15 ft., 8 in. in length and 7 ft., 4 in. in width and permits 3 ft., 6 in. of head room. The preferred launching method is simply to throw the deflated package overboard, as was done in a recent Navy-Coast Guard demonstration from a U.S.C.G. helicopter. By pulling the release cable, the 230-lb. craft is snapped out of its case and ballooned into position by carbon-dioxide gas. An insulated canopy helps to protect the occupants from the weather. The craft is outfitted with survival equipment. . . . The first tubeless tires for aircraft have been developed and are undergoing tests at Goodrich. These new tires, which the company indicates will be used first on combat jet aircraft, are said to "assure safer high-speed take-offs and landings, reduce overall weight of aircraft, simplify assembly, and provide more uniform inflation pressure." The basic construction principles of these new aircraft tires are similar to the company's tubeless tires for passenger cars. A layer of special American-made rubber inside the tire seals in the air, thus replacing an inner tube; special ridges molded on the outer sides of the tire seal against loss of air around the rim. . . . Elmer A. Stevens was recently made Treasurer of the company.

• **The Goodyear Tire and Rubber Company . . .** A 20-man circular life raft, made of a rubber-coated nylon fabric, is now being produced to be carried on U.S.A.F. transport planes. This raft, model F-2, can be inflated and ready for use within 30 sec. by jerking a release cable that frees the valve controlling the carbon dioxide. The raft has no top or bottom as such, for both sides are identical in design to permit boarding despite which side turns up in the water. The raft is $12\frac{1}{2}$ ft. in diameter, weighs 108 lbs., and in its carrying case measures 36 by 18 by 18 in. A portable

nylon canopy that can be attached to the outer edge of the raft is reversible, one side being camouflaged a greenish blue and the other side being a brilliant neon red for signaling purposes. Provision is made for attaching a radar reflector to the canopy's mast. Whenever necessary, the raft can be dropped in its carrying case from an aircraft and the carbon dioxide release cord pulled to inflate the raft. . . . A new and improved version of Goodyear Aircraft Corporation's electronic differential analyzer, the L3 GEDA, has been developed.

• **Industrial Sound Control, Inc.** . . . Sound suppression installations for three additional 30-ft. test cells have been ordered by Wright Aeronautical Division of Curtiss-Wright Corporation. This new equipment will use I.S.C.'s new "Soundstream" method of aircraft engine silencing. The company will also do the soundproofing work on 14 test cells for Buick Jet Engine Division of General Motors Corporation and will construct two run-up mufflers for testing engines directly at the airstrip in the plane. The run-up mufflers are for Douglas Aircraft Company, Inc.

• **Lockheed Aircraft Corporation** . . . A smooth-surfaced deicer boot made of a silver-copper-plastic sandwich bonded to an aluminum base has been designed and developed by Lockheed research scientists for use on the wing and tail leading edges of military jet aircraft. The high metal content of these rivetless boots permits the use of up to 75 watts of current per square inch; normal load is 40 watts, applied for a 2-sec. periods at $1\frac{1}{2}$-min. intervals under icing conditions. This type of boat may see commercial applications sometime in the future.

• **Loewy Construction Company, Inc.** . . . A steel extrusion press that has a capacity of 12,000 tons is being built by Loewy within the U.S.A.F.'s Heavy Press Program.

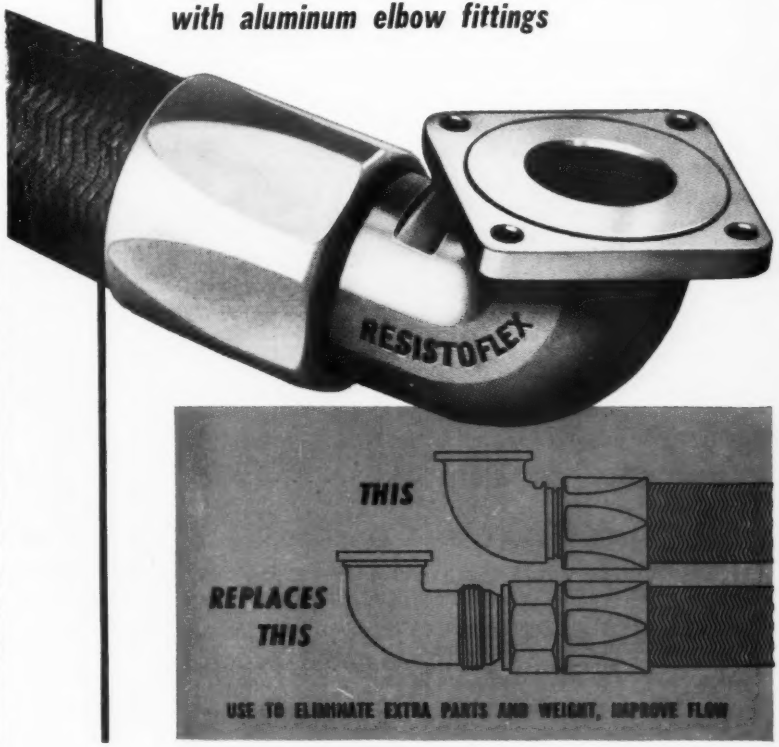
• **McDonnell Aircraft Corporation** . . . With the August 29 delivery of the F2H-2P photoreconnaissance Banshee, McDonnell concluded the production of this particular model. However, the latest Banshee, the F2H-3, is now in production at the plant.

• **Minneapolis - Honeywell Regulator Company** . . . The Department of Personnel and Industrial Relations was recently organized in the Aeronautical Division.

• **North American Aviation, Inc.** . . . The XFJ-2 Fury, powered by a General Electric J-47-GE-2 turbojet engine, has completed successfully its first carrier suitability tests aboard the U.S.S. "Midway." The Fury, which is in the early stages of production at North American's Columbus, Ohio, plant, is armed with four 20-mm. cannons, has a service ceiling of more than 45,000 ft., and has a range of approximately 1,000 miles. . . . The installation of a North American-built kit in the AJ-2 Savage permits this attack plane to be modified within a few hours into a tanker plane using the probe-drogue method of refueling. Droppable auxiliary fuel cells carried in the ship's bomb bay are used to transport the additional fuel needed to supply receiver planes. The AJ-2, the

no adapters needed

when you use RESISTOFLEX hose assemblies with aluminum elbow fittings



■ A Resistoflex hose assembly using *integral elbow fittings* is completely interchangeable with the heavier combination of hose assembly plus adapters. It can help you eliminate needless parts and weight. *Fewer threaded connections also reduce risk of leakage.*

Machined from solid forgings of higher strength aluminum, Resistoflex hose fittings resist vibration and fatigue. Their true bends and smooth interior finish promote full flow with less turbulence or pressure drop. Elbows are compact – fit into tight spots with ample wrench clearance.

See dimensional and test data in the Resistoflex Aircraft Catalog – write and tell us how many copies you want.

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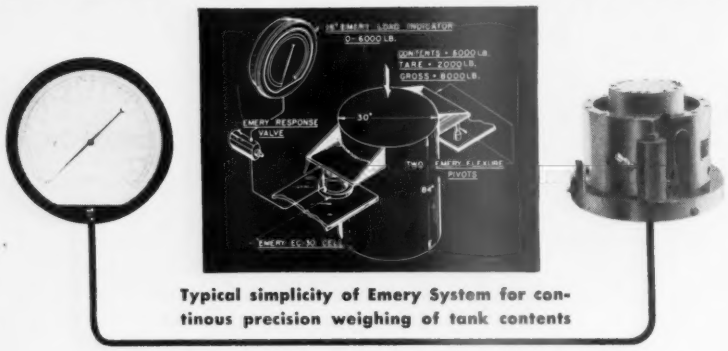

Typical simplicity of Emery System for continous precision weighing of tank contents

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Navy's heaviest carrier-based aircraft, is powered by two Pratt & Whitney R-2800 reciprocating engines and one Allison J-33 turbojet power plant.

• **Piasecki Helicopter Corporation** . . . The H-25 evacuation, assault, and transport helicopter, now in production at Piasecki, has been tagged the "Army Mule."

• **Pratt & Whitney Aircraft Division, United Aircraft Corporation** . . . A ram-jet program, involving the development and construction of ram-jet engines for high-speed guided missiles, has been undertaken for the U.S. Navy. The division has been doing research on ram-jets under U.S.N. auspices since 1946. A ram-jet engine laboratory, or test-stand, a joint Navy Bureau of Aeronautics and United Aircraft project, was built exclusively for the study of ram-jet burners and has been operated by U.A.C.'s Research Department since April 6, 1950. The facility is located on the east side of the department's wind tunnel at Rentschler Airport, East Hartford, Conn. Pratt & Whitney's Andrew Willgoos Turbine Laboratory will be expanded some time this fall to accommodate the ram-jet program.

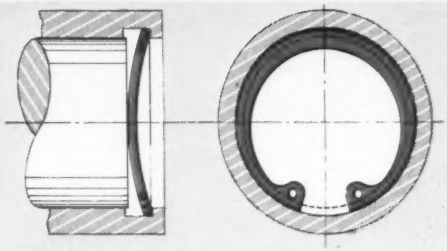
• **Sikorsky Aircraft Division, United Aircraft Corporation** . . . A new antisubmarine helicopter, carrying the Navy designation XHSS-1 and the commercial designation S-58, is now in the works. When completed, it will be a modification of the S-55 helicopter.

• **Socony-Vacuum Oil Company, Inc.** . . . According to the terms of an Armed Services Petroleum Purchasing Agency contract, the company will provide for the service and supply of aviation fuels and oils to U.S. Government aircraft at 19 foreign airports. The contract covers a 1-year period and includes airports in the following areas: Anglo-Egyptian Sudan, Cyprus, French Morocco, the Gold Coast, Greece, Lebanon, Liberia, Portugal and the Azores, Saudi-Arabia, Senegal, Syria, and Turkey.

• **Solar Aircraft Company** . . . The first turbine-driven auxiliary power plant for air-borne use was recently shipped to the U.S.A.F. at Wright-Patterson Air Force Base, Ohio. Designed and built by Solar under a contract with the U.S.A F. Air Materiel Command, this unit will produce electric power for cargo doors and lifts of cargo transports when these aircraft are on the ground with the main engines not running. It will also supply current to operate radio equipment, instruments, and other electrical devices during flight. It runs on either high-octane gasoline or on jet-engine fuel. . . . A new jet-engine-parts facility is scheduled to go into operation this fall. At this facility, a method known as the Solaramic Process is to be used to apply ceramic coatings to General Electric J-47 engine parts.

• **The Sperry Corporation** . . . It was announced in Sperry's annual report that a plant in Joplin, Mo., for the production of hydraulic equipment has been completed. Construction of a Canadian government plant in Montreal to be operated by Sperry Gyroscope Company of Canada, Ltd., is nearly completed, while a guided

if end-play take-up is a problem
one of these special Waldes Truarc rings can solve it



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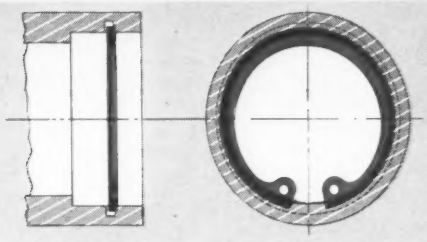
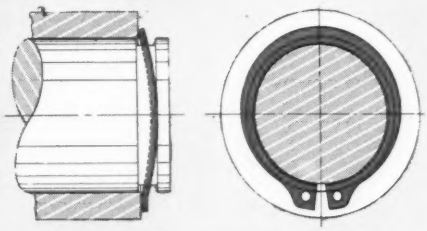
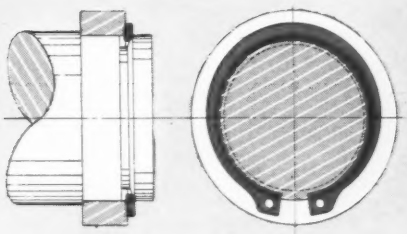
for bore diameters from: .250 — 1.456 in.



series 5002 · internal type
for bore diameters from: 1 — 10 in.



series 5101 · external type
for shaft diameters from: .188 — 1.438 in.



series 5102 · external type
for shaft diameters from: 1 — 10 in.

bowed WALDES TRUARC RETAINING RINGS

Take up end-play resiliently, damp vibrations and oscillations. Bent like a bow out of plane at horizontal center line. The bowed Truarc ring acts in axial direction like a floating spring without losing its tight grip against the bottom of the groove.

Maximum resilient end-play take-up: .015" to .020" depending on size of ring.

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Thousands of manufacturers have already found that Truarc Retaining Rings cut production costs and speed assembly by simplifying product design. But that's not all.

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Fluid Metering Pump Series "M" with capacities from 5 to 15 GPH at 20 psi, 27½ V.D.C. Width 3 1/16", length 6⅞". Weight 2.75 lbs. Single and dual outlet types. Meets all anti-icing requirements.

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Low-Pressure Check or Relief Valve Series 8182 widely used in fuel heater and anti-icing systems. Easily adjustable. Cracking pressure range from 4 psi to 130 psi. Capacities to 36 GPH at 40 psi.

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missile plant at Bristol, Tenn., is under construction with production expected to begin in 1953. This Bristol, Tenn., plant is being built and will be operated for the U.S. Government by Sperry Farragut Corporation.

• **Telecomputing Corporation . . .** The corporation claims that, with the development of the Universal Telereader, faster and more accurate measurements of film and oscillograph records are now possible. The Universal Telereader measures records ranging from 16- and 35-mm. film to 12-in. oscillograph paper up to 100 ft. in length. It is also said to be able to handle either translucent or opaque records. Three interchangeable projection lenses, permitting record magnification of 2x, 4x, and 11x, are provided with the Telereader. When used with companion instruments such as the corporations Telecordex and a summary punch, the Telereader is designed to print its measurements in decimal form on a typewriter supplied with the Telecordex, as well as to record such information into punched cards.

• **The H. I. Thompson Company . . .** Thompson has formed a Canadian corporation that has built a plant at Guelph, Ontario, Canada. This new Thompson plant is scheduled to produce Refrasil high-temperature removable insulating blankets for jet aircraft and other industrial applications, as well as Thermo-Cousti low-temperature acoustical insulation for aircraft cabin and cockpit interiors.

• **Vickers, Inc. . . .** The complete line of variable displacement pumps of the Vickers piston design is described in the new Vickers Brochure 5203, which may be secured from the corporation's Detroit office. These pumps are available in standard sizes ranging up to 23.84 gals. per min. (1,500 r.p.m.).

• **Westinghouse Electric Corporation . . .** A fellowship fund named after and honoring the late Leon R. Ludwig has been established to help promising young engineers and scientists of Westinghouse to continue their studies at a graduate level. To be eligible for a fellowship, a candidate must have shown marked ability in engineering or scientific fields and must have been in the employ of Westinghouse for at least 2 years.

I.A.S. Sections

Atlanta Section

Edith H. Lively
Secretary

The Atlanta Section recently completed its formal organization with the election of its first permanent slate of officers who are as follows: Chairman, George W. Baughman; Vice-Chairman, George K. Williams; Secretary, Edith H. Lively; and Treasurer, John J. Harper. The Board Members are: Robert W. Middlewood, Perry M. Banta, Don W. Dutton, Floyd Addison, and David F. Berry.

A Board meeting was held on August 5, at which time the following

chairmen of standing committees were appointed: Membership, Bert Bricker; Program, George K. Williams; Nominating, Don W. Dutton; Welcoming, Albert D. Brown; and Meeting and Arrangements, Arnold L. Ducoff.

Forty-two members were on the roster as of last August. A total membership of 100 is the goal for the 1952–1953 year. The present membership is drawn largely from Lockheed Aircraft Corporation's recently activated Georgia Division at Marietta, Ga., which has imported its personnel from many parts of the country. Georgia Institute of Technology has added to its aeronautical faculty and prestige.

Dayton Section

Charles M. Mitchell, Jr.
Secretary

The officers for 1952–1953 are: Chairman, W. A. Barden; Vice-Chairman, C. L. Hall; Secretary, C. M. Mitchell, Jr.; and Treasurer, G. L. Herz. The Advisory Board consists of A. F. Dernbach, W. D. Dodd, R. W. Hoeflein, C. I. Lathram, G. J. McTigue, J. F. Haines, E. Kotcher, and F. Sweet.

Montreal Section

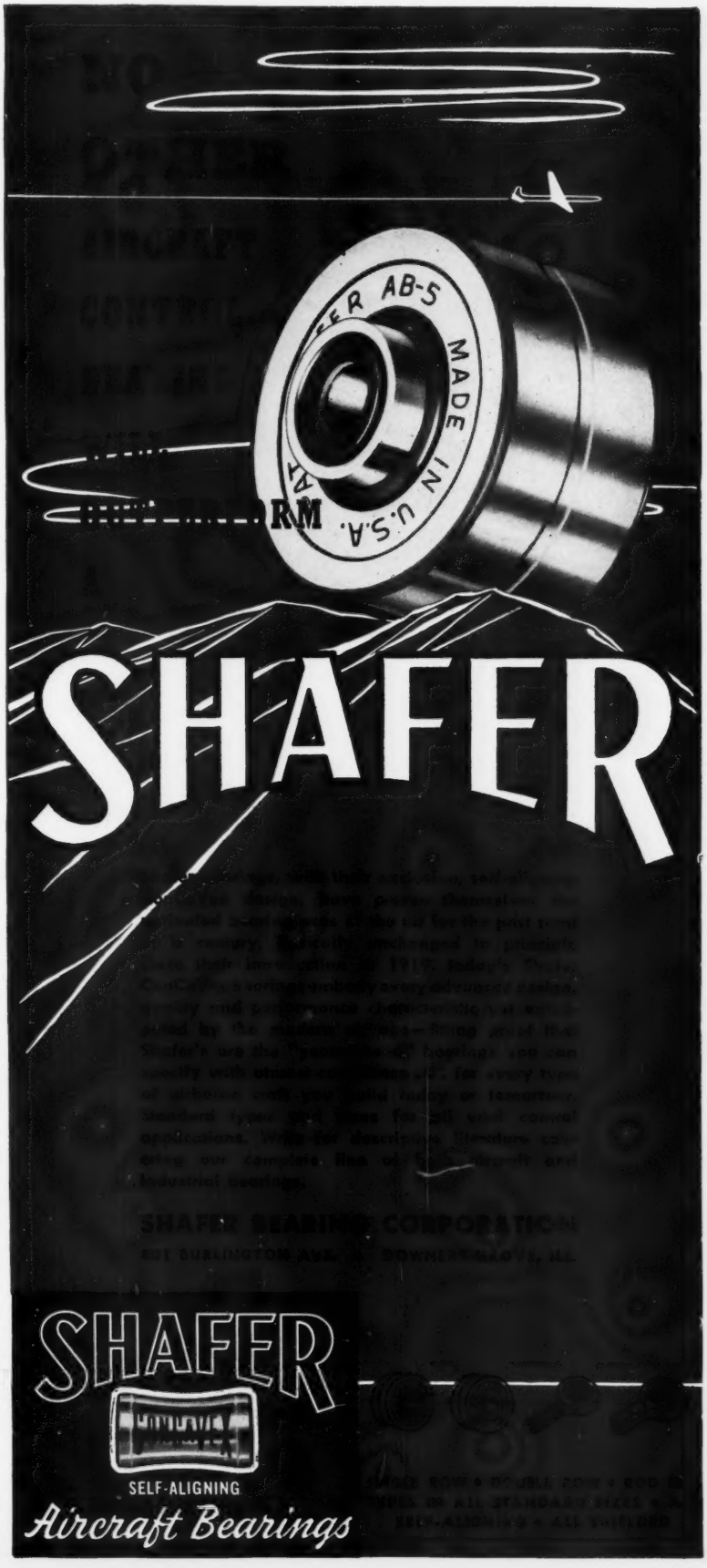
H. V. Braceland
Secretary

In Mr. Schaefer's absence, Mr. Higgins, Vice-Chairman of the section, presided. Mr. Higgins opened the meeting by stating that the Secretary and Treasurer would give the customary yearly reports, and, then, since this was to be the last 1951–1952 meeting, the election of officers would take place.

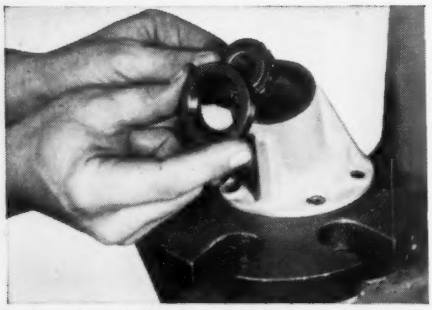
The following slate of officers and Advisory Committee was proposed, voted on, and accepted: Chairman, E. H. Higgins; Vice-Chairman, A. E. Ades; Secretary, B. Kaganov; and Treasurer, R. H. Guthrie. The Advisory Committee consists of: A. Bandi, J. W. R. Drummond, W. K. Ebel, E. B. Schaefer, H. V. Wright, and Prof. D. Mordell.

After the elections, Messrs. Rosenthal and Abichandani's joint paper entitled "Some Aero-Dynamic Factors in Wing Design of Transonic Aircraft," was excellently presented by Mr. Rosenthal.

The speaker covered many of the definitions pertaining to high-speed flight and indicated their exact ap-



J-M Clipper Seals fly with the Sikorsky HO5S helicopter...



Clipper Seal being installed in the intermediate gear box of the Sikorsky HO5S helicopter to seal oil in, keep abrasives out.

Photograph and cross section of Type LPD Clipper Seal. This is just one of numerous styles available to solve tough sealing problems.

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plication to transonic speeds, which, he stated, were in a range extending from 20 per cent below to 20 per cent above the speed of sound.

Mr. Rosenthal indicated that information on the transonic region must be obtained experimentally, since prediction of airfoil characteristics was unsatisfactory at combined subsonic and supersonic speeds.

The use of sweepback, low aspect ratio, and thin wings was explained, and the prediction was given that, since transonic flight introduces design compromises, the trend, in general, would be toward lower wing loading, sweepback angles greater than 40°, aspect ratios below 4, and profiles below 8 per cent in thickness ratios.

San Diego Section

H. L. Braasch
Secretary

A San Diego Section meeting was held on August 14 in the Marine Room of the Hotel San Diego. Dinner was preceded by a short social hour in the lounge.

The San Diego Section was fortunate to have as its speaker Capt. Nicholas A. Draim, U.S.N., who talked on the subject, "Impressions of a Naval Attaché in Moscow." Captain Draim was introduced by Earl Hinz, Chairman of the Membership Committee, who acted as Technical Chairman for the evening.

Captain Draim recently returned to the United States following 2 years of service as Naval Attaché and Naval Attaché for Air at the American Embassy in Moscow. This tour of duty was preceded by a long and impressive career with the U.S. Navy. Since 1926, he has been assigned to the Bureau of Aeronautics doing all phases of engineering associated with Naval aircraft development. Captain Draim is an Associate Fellow of the Institute of the Aeronautical Sciences and a member of the Bar of the U.S. Court of Customs and Appeals and of the Supreme Court.

In his talk, Captain Draim gave vivid expression to his everyday experiences as a Naval Attaché in Moscow. He told of his impressions of the life of the average person under Communist rule. His talk indicated that Communist living standards are certainly not enviable. The presentation was highlighted by colored slides taken of the Kremlin. An active question and answer period followed the talk.

Approximately 120 members and guests attended the meeting. Following Captain Draim's address, W. C. Heath, Chairman of the San Diego Section, adjourned the meeting.

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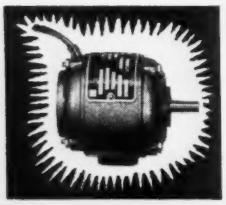

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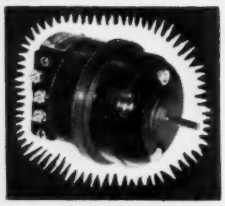

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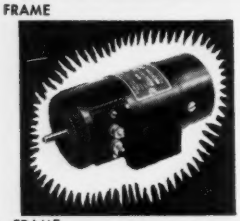

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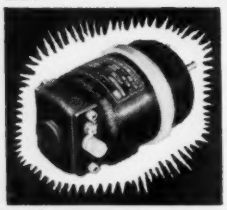

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Members Elected

The following applicants for membership or applicants for change of previous grades have been admitted since the publication of the list in the last issue of the REVIEW.

Elected to Associate Fellow Grade

Dornberger, Walter R., Dr. of Engrg., Guided Missile Design Specialist; Cons. to the V.-P. of Engrg., Bell Aircraft Corp.

Mettam, Herbert A., M.A., Sr. Principal Scientific Officer, Ministry of Supply, Royal Aircraft Establishment (Farnborough).

Transferred to Associate Fellow Grade

Bergere, Emric W., In charge of Production Methods, Engrg. Dept., Douglas Aircraft Co., Inc. (Long Beach).

Hoerner, Sighard F., Dr. Ing., Aero dynamicist & Hydrodynamicist, Gibbs & Cox, Inc.

Kurzweg, Hermann H., Ph.D., Chief, Aeroballistic Research Dept., Naval Ordnance Lab. (White Oak).

Middlewood, Robert W., B.S., Chief Engr., Lockheed Aircraft Corp. (Georgia Div.).

Wodrich, Edmund G., B. of Ae.E., Maj., U.S.A.F.; Chief, Missile Unit, Devel. & Test Sect., Office of Deputy for Operations, 6540th Missile Test Wing, Holloman A.F.B.

Elected to MEMBER Grade

Anderson, Jack A., Sr. Design Engr., A. V. Roe Canada, Ltd. (Malton).

Benson, Robert M., B.S.M.E. (Aero.), Chief Research Engr., Instrument Associates of California.

Boster, Robert D., Jr., B.S., Sales Engr., Huck Manufacturing Co.

Brown, Albert D., B.S.—Engrg., Proj. Engr., Lockheed Aircraft Corp. (Georgia Div.).

Clarkson, John, B.S.C.E., Chief Stress Engr., Prewitt Aircraft Co.

Cone, Fred P., B.S.Ae.E., Stress Analyst "A," Douglas Aircraft Co., Inc. (Long Beach).

Dahm, Werner, Dipl. Ing., Chief, Aerodynamics Sect., Guided Missile Devel. Group, Redstone Arsenal, Dept. of the Army.

de los Santos, S., D.Sc., Aero. Engr GS-12, David Taylor Model Basin, Dept. of the Navy.

Driskel, Don W., Partner-Chief Engr., Haskel Engineering Associates.

Foster, Douglas V., B.Sc. (Math.), Aerodynamicist, Joy Manufacturing Co.

Hensley, Reece V., B.S., Aero Research Scientist, L.F.P.L., N.A.C.A.

Higgins, Thomas G., B.A.Sc., Stress Engr., A. V. Roe Canada, Ltd. (Malton).

Hoecker, Wade L., Jr., B.S., Design Engr. "A," Special Weapons Div., Northrop Aircraft, Inc.

Jordan, Harold J., B.S., Sect. Engr., Components Dev. Facilities, Aircraft Gas Turbine Div., General Electric Co.

Looker, Robert, B.S., Sales Mgr., Huck Manufacturing Co.

Montanaro, John, Aerodynamicist & Tech. Asst., Fairey Aviation Co., Ltd.

Rainbird, William J., D.C.Ae., Assoc. Prof. of Mech. Engrg., School of Engrg., Canterbury University College (Christchurch, N.Z.).

Rey, William K., M.S. in C.E., Assoc. Prof. of Aero Engrg., University of Alabama.

Ryan, Matthew G., B.A.Sc., Sr. Aerodynamicist, A. V. Roe Canada, Ltd.

See, John A., B.C.E., Flight Test Engr., Boeing Airplane Co. (Seattle).

Unfried, Charles O., Sales Service Engr., Huck Manufacturing Co.

Wall, Hubert G., B.S., Admin. Engr., Accessory Turbine Engrg., Aircraft Gas Turbine Div., General Electric Co.

Wurts, John, B.S. in Ae.E., Lead Designer, Chance Vought Aircraft Div., United Aircraft Corp. (Dallas).

Transferred to MEMBER Grade

Beckelman, Jack D., M.S. in Ae.E., Lt. Col., U.S.A.F.; Pilot & Chief, Weapons Design & Devel. Div.; Deputy Chief of Staff—Research & Devel., Kirtland A.F.B.

Lee, Alan C., B.S. in Ae.E., Design Engr. "B," Power Plant Group, Douglas Aircraft Co., Inc. (Long Beach).

Marhefka, Robert J., B.S. in Ae.E., Engrg. Designer "B," Boeing Airplane Co. (Seattle).

Mattice, Hubert C., M. of Ae.E., Instr., Aero. Engrg., Rensselaer Polytechnic Institute.

McRae, Forbes W., Jr., B.S. in M.E., Group Engr., Boeing Airplane Co.

Elected to Associate Member Grade

Bernard, Thomas N., Sales Engr., Huck Manufacturing Co.

Busch, Gerald A., M.S. in Economics, Asst. to V.-P.—Operations, Slick Airways, Inc.

Clute, Ray V., Sales Engr., Huck Manufacturing Co.

Dobbe, Frank A., V.-P. in Charge of Sales, Huck Manufacturing Co.

Huck, Louis C., Jr., Northeastern District Mgr., Huck Manufacturing Co.

Loyola, Marcos, Asst. Air Attaché, Purchasing Div., Chilean Air Force Commission, Chilean Embassy (Washington, D.C.).

Martin, Allan G., B.A., Sales Engr., Huck Manufacturing Co.

Mather, T. W., B.A., Sales Engr., Huck Manufacturing Co.

Previte, Benjamin A., Service Rep., Link Aviation, Inc.

Stamy, Donald J., B.S., Asst. Sales Mgr., Huck Manufacturing Co.

Upton, A. Joe, B.A., Sales Engr., Huck Manufacturing Co.

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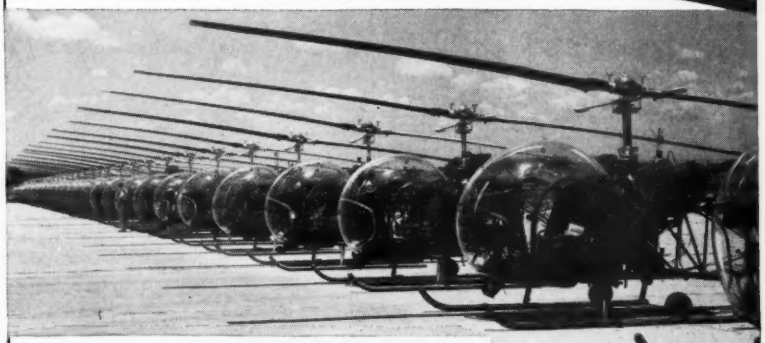
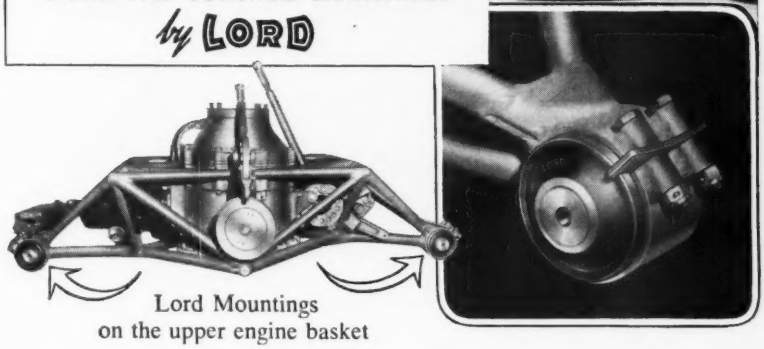


VIBRATION CONTROL MOUNTINGS *by* LORD



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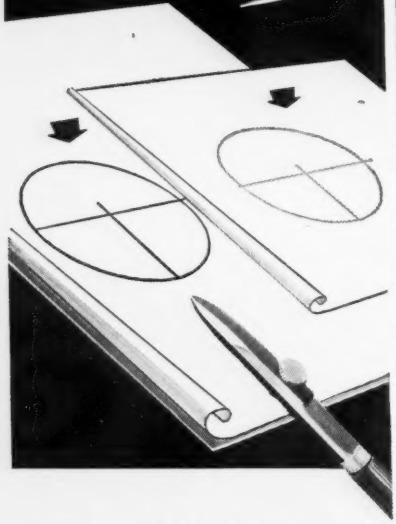

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Elected to Technical Member Grade

Campbell, Francis S., B.E.E., Field Engr., Sperry Gyroscope Co., Div., The Sperry Corp.

Gregory, John R., B. of Applied Sc., Liaison Engr., Thompson Products, Ltd. (Canada).

Lee, Charles H., Jr., B.S. (M.E.), B.A. (Physics), Mech. Design Engr., General Electric Co. (Lynn).

Luczynski, Mitchell, B.S., Draftsman, Chicago Aerial Survey.

Pinsley, Edward, S.M., Research Engr., United Aircraft Corp. (East Hartford).

Price, Zachary S., M.S. (Physics), Aerodynamics Engr., Consolidated Vultee Aircraft Corp. (San Diego).

Revell, James D., B.S. (Engrg.), Engrg. Asst. "A," Thermodynamics Sect., Northrop Aircraft, Inc.

Suchoversky, Thor, Dipl. Ing., E T.H., Engr., Aluminum Werke (Switzerland).

Wylie, Robert L., B.S.Ae.E., Jr. Engr., Chance Vought Aircraft Div., United Aircraft Corp. (Dallas).

Transferred to Technical Member Grade

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Bauer, Norman D., B.S. in Ae.E., Design Engr., Ramjet Sect., Marquardt Aircraft Co.

Begin, Robert E., B.S. in Ae.E., Jr. Stress Analyst, Sikorsky Aircraft Div., United Aircraft Corp.

Benschine, Edward, Jr., Capt., U.S.A.F.; Aero. Engr., A.R.D.C., Wright-Patterson A.F.B.

Burk, Charles H., B.S., Jr. Engr.-Aerodynamicist, Chance Vought Aircraft Div., United Aircraft Corp.

Bush, Harry L., M.S.E. (Aero.), Maj., U.S.A.; Student, 1st Student Officer Battery, Fort Sill (Okla.).

Davis, Joseph G., B.S.Aero., Engr., Douglas Aircraft Co., Inc. (Santa Monica).

Deutsch, Jeffrey S., B.S., 2nd Lt., U.S.A.F.; Base Flight Maint. Officer, 804th Oprs. Sq., 804th Air Base Group, Hunter A.F.B.

Eberle, Harold J., M.S.E., Lt., U.S.A.F.; Instr., Exp. Test Pilot School, Edwards A.F.B.

Etherington, Richard E., B.S. in Ae.E., Jr. Engr., Power Plant Sect., Beech Aircraft Corp.

Faehl, Kenneth C., B. of Ae.E., Engr. II, ARO, Inc.

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Fischetti, Thomas L., B. of Ae.E., Aero. Research Intern, N.A.C.A., Langley A.F.B.

Gould, Ansel V., B.S.E., Ens., U.S.S. "Des Moines," U.S.N.

Grubbs, Virgil A., Jr., Sr. Draftsman, Goodyear Aircraft Corp.

Handlewich, Robert M., Analytical Engr., Pratt & Whitney Aircraft Div., United Aircraft Corp.

Hayman, Thomas, B.A.Sc., Stress Engr., Outer Wing Group, A. V. Roe Canada, Ltd.

Hendricks, Joseph L., Jr., B.S., Asst. Proj. Engr., O. & R. Dept., N.A.S. (Norfolk).

Horn, Walter F., Jr., B.S., Jr. Engr.—Research, Allied Research Associates, Inc.

Houghton, Paul E., B.S.M.E. (Aero.), Stress Analyst "C," North American Aviation, Inc. (Downey).

Jarvineva, Elias A., M.Sc. in Engrg. (Aero.), Design Engr., Valmet Oy. Lentokonetehtaat (Finland).

Johnson, Lloyd H., B.S. in Ae.E., 2nd Lt., U.S.A.F.; Aircraft Maint. Engr., 810th Air Base Group, Biggs A.F.B.

Judge, Dorothy J., B.S.Ae.E., Mathematician "A," Aerodynamics Group, Douglas Aircraft Co., Inc. (Long Beach).

Kilpatrick, David F., Design Engr., Coleman Engineering Co.

Laisure, Corliss U., B.S. in Ae.E., 2nd Lt., U.S.A.F.R.

Leff, Robert L., B.S. in Ae.E., 2nd Lt., U.S.A.F.R.; Student, Air Force Institute of Technology, Wright-Patterson A.F.B.

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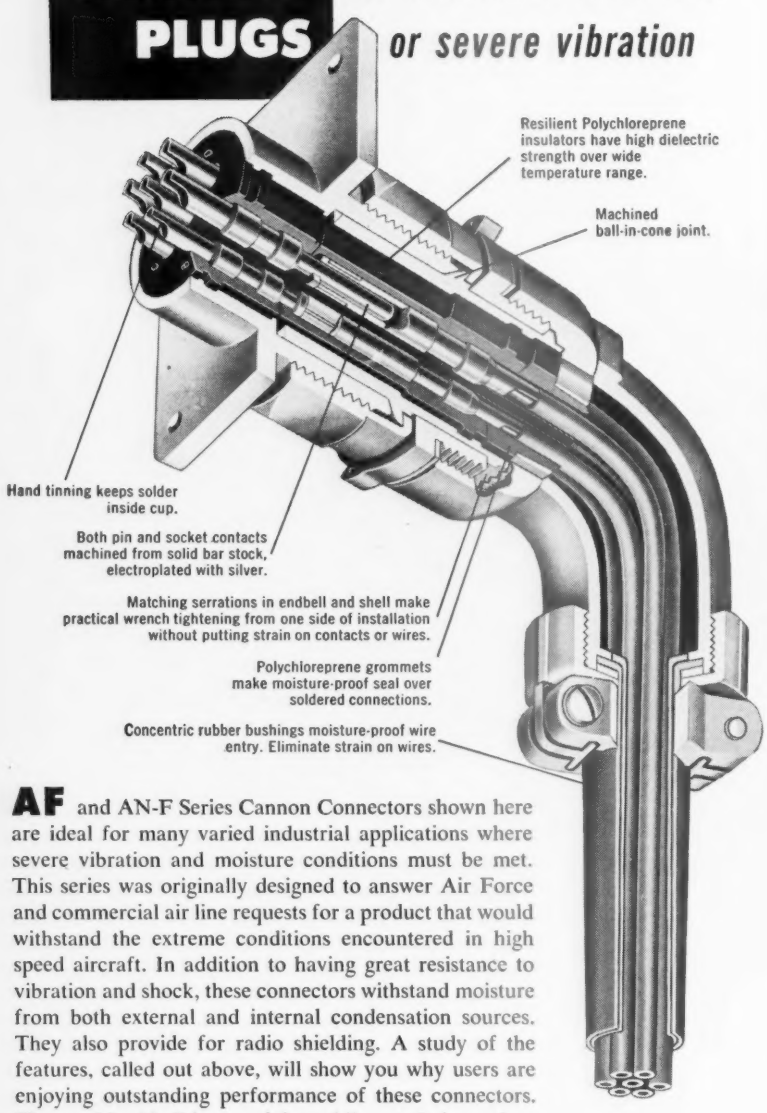
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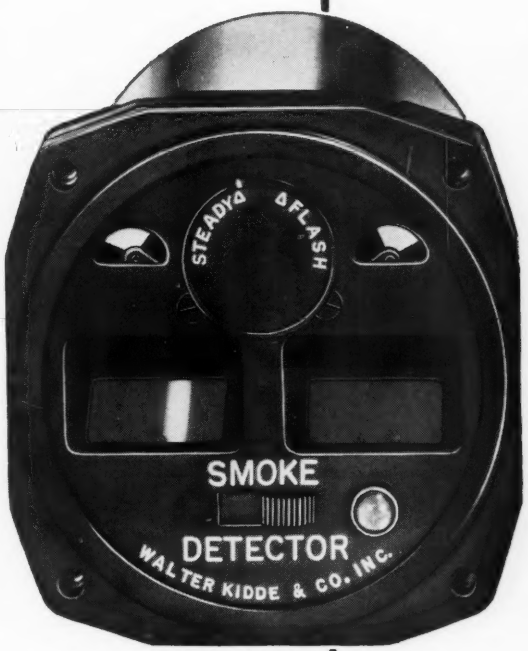

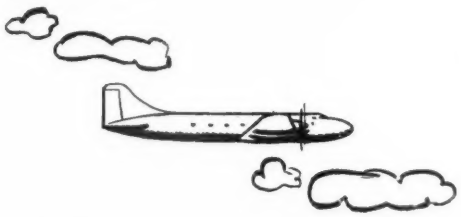

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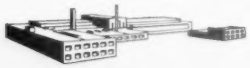

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Aeronautical Reviews

A Guide to the Current Literature of Aeronautical Research and Engineering

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Aerodynamics (2)

Prophecy and Achievement in Aeronautics. Harry M. Garner. (40th Wilbur Wright Memorial Lecture, May 29, 1952). *Royal Aeronautical Society, Journal*, Vol. 56, No. 499, July, 1952, pp. 493–510, illus. 11 references. A review of aeronautical progress; aerodynamic studies that have led to improved design and performance of aircraft; future developments.

BOUNDARY LAYER & THERMOAERODYNAMICS

On the Determination of the Transition Point from Measurements of the Static Pressure Along a Surface. H. Wijker. *Netherlands, Nationaal Luchtvaartlaboratorium, Amsterdam, Report No. A.1210* (*Reports and Transactions*, Vol. 16, pp. A7–A17), 1951. 11 pp., illus. 20 references.

Calculation, for both laminar and turbulent boundary layers, of the difference between the static pressure at the edge of the boundary layer and at the surface of a flat plate at zero incidence in parallel flow; application of the results to a study of existing methods of determining the transition point.

Experiments on Distributed Suction Through a Rough Porous Surface. Cambridge University Aeronautical Laboratory. *Gt. Brit., Aeronautical Research Council, Current Papers No. 84*, 1952 (June 20, 1951). 7 pp., illus. 1 reference. British Information Services, New York. $0.40.

Flight test data with suction applied through a slightly rough porous surface to maintain the laminar boundary layer show that, with a uniform surface pressure, two limiting speeds exist: an upper limit above which no reasonable suction would prevent transition to turbulence, and a lower limit below which the surface can be regarded as aerodynamically smooth.

Structural Aspects of Suction Wings. E. H. Mansfield. *Gt. Brit., Aeronautical Research Council, Current Papers No. 87*, 1952 (June, 1951). 25 pp., illus. British Information Services, New York. $1.15. Practicability of achieving low-wing drag by stabilizing the boundary layer by distributed suction; structural design problems and weight penalties.

The Production of Lift Independently of Incidence—The Thwaites Flap. I, II. B. Thwaites. *Gt. Brit., Aeronautical Research Council, Reports and Memoranda No. 2611*, 1952 (November, 1947). 20 pp., illus. 2 references. British Information Services, New York. $1.25.

Theoretical analysis of the Thwaites Flap method that uses boundary-layer suction to increase lift of an airfoil in a uniform stream independently of the airfoil's incidence. Experimental data on a wholly porous cylinder fitted with a Thwaites Flap show the actual lift generated.

Notes and Graphs for Boundary Layer Calculations in Compressible Flow. W. F. Cope. *Gt. Brit., Aeronautical Research Council, Current Papers No. 89*, 1952 (August 24, 1951). 22 pp., illus. 6 references. British Information Services, New York. $0.90.

Formulas for calculating skin friction coefficients and boundary-layer parameters for Mach Numbers up to 4 for a laminar boundary layer with a sinusoidal velocity distribution and for turbulent boundary layers having power law and log law velocity distributions.

Boundary Layer Measurements in the UTIA 5- by 7-Inch Supersonic Wind Tunnel. J. Ruptash. *Toronto, University, Institute of Aerophysics, Report No. 16*, May, 1952. 46 pp., illus. 14 references.

Total pressure surveys and schlieren photographs of the boundary-layer build-up in the nozzle of the UTIA 5- by 7½in. supersonic tunnel; effects of corner fillets, and of their radii, on the boundary-layer thickness.

Surface Conduction of the Heat Transferred from a Boundary Layer. T. Nonweiler. *College of Aeronautics, Cranfield, England, Report No. 59*, May, 1952. 17 pp., illus. 2 references.

Analysis of the effects of thermal conductivity on the temperature distribution in the skin of a body due to heat transfer from the boundary layer; variation of these effects with speed and altitude.

Readers' Forum: On Boundary-Layer Temperature Recovery Factors. B. des Clers and J. Sternberg. *Journal of the Aeronautical Sciences*, Vol. 19, No. 9, September, 1952, pp. 645, 646, illus. 1 reference.

Readers' Forum: Hooke's Gas in Aerothermodynamics. Ennio Mattioli. *Journal of the Aeronautical Sciences*, Vol. 19, No. 9, September, 1952, pp. 642, 643. 6 references.

Turbulent Energy Considerations in Turbulent Boundary-Layer Flow. R. A. Wallis. *Australia, Department of Supply and Development, Aeronautical Research Laboratories, Aerodynamics Note No. 86*, November, 1946. 11 pp. 13 references.

Investigation of the turbulent motion energy equations for rapidly accelerating or decelerating flow, emphasizing the Reynolds normal stresses in suction experiments to provide a means of measurement near the separation point when skin friction cannot be estimated by the von Kármán momentum equation.

Readers' Forum: The von Kármán Integral Method As Applied to a Turbulent Boundary Layer. Nguyen Van Le. *Journal of the Aeronautical Sciences*, Vol. 19, No. 9, September, 1952, pp. 647, 648, illus. 4 references.

The Re-Attachment of a Turbulent Boundary-Layer Behind a Spoiler. B. G. Newman. *Australia, Department of Supply and Development, Aeronautical Research Laboratories, Report No. A. 64*, October, 1949. 34 pp., illus. 14 references.

Investigation of the growth and separation of the turbulent boundary layer on a two-dimensional wing with rear stalling characteristics, forcing a local separation by means of a spoiler; a reattached, but highly fluctuating, turbulent boundary layer was found to exist behind the spoiler; measurements of the mean velocity distribution and the pressure behind the spoiler.

The Measurement of the Reynolds Stresses in a Circular Pipe As Means of Testing a Hot Wire Anemometer. B. G. Newman and B. G. Leary. *Australia, Department of Supply, Aeronautical Research Laboratories, Report No. A. 72*, November, 1950. 58 pp., illus. 9 references.

Measurements of the direct and shearing turbulent stresses in a circular pipe at a Reynolds Number of 1.15×10^5 as a method of testing and calibrating a hot-wire anemometer that was designed to study the growth and separation of the turbulent boundary layer.

CONTROL SURFACES

Note on the Frise Aileron. H. H. B. M. Thomas and E. R. Crabbe. *Gt. Brit., Aeronautical Research Council, Reports and Memoranda No. 2502*, 1952 (October, 1946). 16 pp., illus. 23 references. British Information Services, New York. $1.15. General characteristics of the Frise aileron; development of a method of estimating hinge-moment characteristics.

Readers' Forum: Reply to Comments on "Horizontal Tail Loads in Abrupt Pull-Ups from Level Flight." J. L. Decker. *Journal of the Aeronautical Sciences*, Vol. 19, No. 9, September, 1952, pp. 643, 644, illus. 4 references.

FLUID MECHANICS & AERODYNAMIC THEORY

Readers' Forum: A Third Kind of "Incompressible" Fluid. A. Martinot-Lagarde. *Journal of the Aeronautical Sciences*, Vol. 19, No. 9, September, 1952, p. 640. 1 reference.

Approximation of the heat term of the energy equation for a third class of incompressible flows—i.e., the flow of most real liquids. The analysis emphasizes the pressure term at the expense of other thermodynamic variables.

The Drag on Slender Pointed Bodies in Supersonic Flow. G. N. Lance. *Quarterly Journal of Mechanics and Applied Mathematics*, Vol. 5, Part 2, June, 1952, pp. 165–177, illus. 3 references.

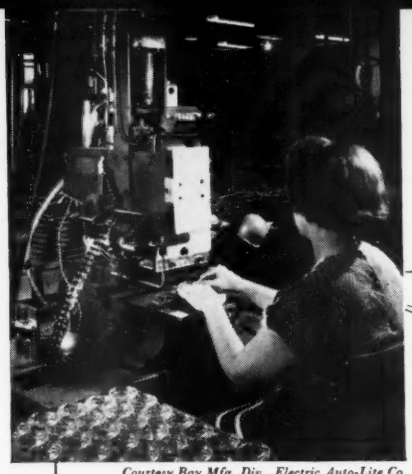
The linearized theory of supersonic flow is used to determine the wave drag on slender pointed bodies both of revolution and with an arbitrary cross section. A simple deduction of von Kármán's expression is given for this drag and two alternative expressions are obtained by distinct methods.

Readers' Forum: The Prandtl Membrane Analogy for Temperature Fields with Permanent Heat Sources or Sinks. Paul J. Schneider. *Journal of the Aeronautical Sciences*, Vol. 19, No. 9, September, 1952, pp. 644, 645, illus. 3 references.

Outline of the theory and mechanics of the Prandtl membrane analogy; extension to experimental solutions for steady-state two-dimensional temperature distributions with permanent heat sources or sinks, including cases of nonregular boundary shape.

Interaction of Oblique Shock Waves with Regions of Variable Pressure, Entropy, and Energy. W. E. Moeckel. *U.S., N.A.C.A., Technical Note No. 2725*, June, 1952. 34 pp., illus. 6 references.

Development of equations for propagation of oblique shock waves of arbitrary strength through supersonic regions in which pressure, energy, or entropy are continuously variable; development of a wave-interaction procedure for determining supersonic



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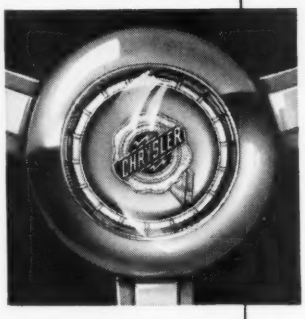

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portions of the flow downstream of the shock and of an approximate method for dealing with imbedded subsonic regions.

The Head-On Collision of Two Shock Waves and a Shock and a Rarefaction Wave in One-Dimensional Flow. D. G. Gould. *Toronto, University, Institute of Aerophysics, Report No. 17*, May, 1952. 432 pp., illus. 11 references.

Review of the theory, following the methods of Courant and Friedrichs, of the head-on collision of two shock waves and a shock and a rarefaction wave in one-dimensional flow; experimental observations of the collision.

On the Interaction of Rarefaction Waves in a Shock Tube. J. A. Steketee. *Toronto, University, Institute of Aerophysics, Review No. 4*, March, 1952. 46 pp., illus. 6 references.

Analysis of the one-dimensional propagation of rarefaction waves; theory of a shock tube where the compression chamber contains an ideal gas and the expansion chamber is completely evacuated, and the initial motion is a complete centered rarefaction wave; explicit calculation of the interaction region for a monatomic and a diatomic gas; application to a shock tube where the expansion chamber is not evacuated.

Supersonic Flow in a Shock Tube of Divergent Cross-Section. Edwin K. Parks. *Toronto, University, Institute of Aerophysics, Report No. 18*, May, 1952. 58 pp., illus. 11 references.

Theoretical and experimental analysis of the diffraction of a plane shock wave at a convex corner and as it passes through a Busemann-type nozzle in a shock tube of divergent cross section.

INTERNAL FLOW

The Development of Cascade Profiles for High Subsonic Potential Flows. Hsuan Yeh. *Journal of the Aeronautical Sciences*, Vol. 19, No. 9, September, 1952, pp. 630–638, illus. 13 references.

Development of a theoretical method for designing cascade profiles to satisfy prescribed inlet and exit flow conditions and cascade solidity. The simplest possible mapping function is found which will generate the desired cascade profile; the compressibility of the flow is represented by a suitably chosen linear pressure-volume relationship (the Kármán-Tsien relationship).

Detailed Computational Procedure for Design of Cascade Blades with Prescribed Velocity Distributions in Compressible Potential Flows. George R. Costello, Robert L. Cummings, and John T. Sinnette, Jr. (*U.S., N.A.C.A., Technical Note No. 2281*, 1951). *U.S., N.A.C.A., Report No. 1060*, 1952. 14 pp., illus. 1 reference. Superintendent of Documents, Washington. $0.20.

Readers' Forum: Secondary Flow in Cascades. H. G. Loos and J. Zwaaneveld. *Journal of the Aeronautical Sciences*, Vol. 19, No. 9, September, 1952, pp. 646, 647, illus. 4 references.

Two-Dimensional Flow on General Surfaces of Revolution in Turbomachines. John D. Stanitz and Gaylord O. Ellis. *U.S., N.A.C.A., Technical Note No. 2654*, March, 1952. 44 pp., illus. 7 references.

Multistage Radial Turbines. P. F. Martinuzzi. *American Society of Mechanical Engineers, Transactions*, Vol. 74, No. 5, July, 1952, pp. 663–673, illus. 2 references.

Theoretical development of a multistage inflow turbine for gas-turbine use in which all the stages are carried on a single rotor disc; calculation of a numerical example.

An Approximate Calculation of the Laminar Nonisothermal Flow in a Circular Pipe. I—The Case of Invariable Viscosity (Poiseuille Flow). Michio Ohji. *Kyushu, Imperial University, Research Institute for Applied Mechanics, Reports*, Vol. 1, No. 2, April, 1952, pp. 23–38, illus. 14 references. Development of a method of calculation, analogous to the von Kármán-Pohlhausen approximation, for a laminar boundary layer with invariable viscosity.

Discharge Measurements by Means of Cylindrical Nozzles. *American Society of Mechanical Engineers, Transactions*, Vol. 74, No. 5, July, 1952, pp. 825–835, illus. 11 references.

Supersonic Diffusers. J. Łukasiewicz. *Gt. Brit., Aeronautical Research Council, Reports and Memoranda No. 2501*, 1952 (June, 1946). 30 pp., illus. 19 references. British Information Services, New York. $1.80. Theoretical analysis of various types of supersonic diffusers; review of experimental data; diffuser operation at other than the design Mach Number.

The Laminar Motion of a Plane Symmetrical Jet of Compressible Fluid. D. G. Toose. *Quarterly Journal of Mechanics and Applied Mathematics*, Vol. 5, Part 2, June, 1952, pp. 155–164, illus. 7 references.

Development of a closed analytical solution for the laminar motion of a plane symmetrical jet of compressible fluid, assuming a Prandtl Number of unity and assuming that the dynamic viscosity μ depends on the absolute temperature t according to the relation $\mu \propto t$.

PERFORMANCE

Optimum Climb Technique for a Jet Propelled Aircraft. L. Kelly. *College of Aeronautics, Cranfield, England, Report No. 57*, April, 1952. 50 pp., illus. 3 references.

An exact analytic method for determining the optimum climb technique for jet-propelled aircraft, using the concept of energy height which includes the geometric height and the height equivalent of the kinetic energy; evaluation of the end conditions; method of obtaining the optimum climb relationship for any particular aircraft; typical climb data for R.A.F. fighter aircraft.

STABILITY & CONTROL

End Corrections for Frequency Response Obtained by Laplace Transformations. G. M. Andrew. *U.S., Air Force, Flight Test Center, Edwards A.F.B., Calif., Report No. AFFTC 52-15*, February 7, 1952. 30 pp., illus. 4 references.

Development, using the Laplace transform, for the end correction of frequency response for step, ramp, and damped sine curves. Dynamic airplane behavior is recorded as the time history of different parameters.

The Effect of Aerodynamic Lag on the Snaking Motion of Aeroplanes. A. I. van de Vooren and J. Yff. *Netherlands, Nationaal Luchtvaartlaboratorium, Amsterdam, Report No. F.107*, March 22, 1952. 32 pp., illus. 7 references.

An investigation of the influence of nonstationary aerodynamics on the stability derivatives used in making calculations with two degrees of freedom (yaw and rudder deflection). The dependence on the frequency is given in the form of correction factors to be applied to the quasi-steady values of the derivatives.

Analysis of Means of Improving the Uncontrolled Lateral Motions of Personal Airplanes. Marion O. McKinney, Jr. (*U.S., N.A.C.A., Technical Note No. 1997*, 1949). *U.S., N.A.C.A., Report No. 1035*, 1951. 9 pp., illus. 4 references. Superintendent of Documents, Washington. $0.15.

A Theoretical Analysis of the Effect of Time Lag in an Automatic Stabilization System on the Lateral Oscillatory Stability of an Airplane. Leonard Sternfield and Ordway B. Gates, Jr. (*U.S., N.A.C.A., Technical Note No. 2005*, 1950). *U.S., N.A.C.A., Report No. 1018*, 1951. 12 pp., illus. 11 references. Superintendent of Documents, Washington. $0.20.

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the laws of continuum theory flow apply (approximately $M = 3$–10).

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$$1-(1/2A\sqrt{M^2-1})$$

where A = aspect ratio and M = free-stream Mach Number.

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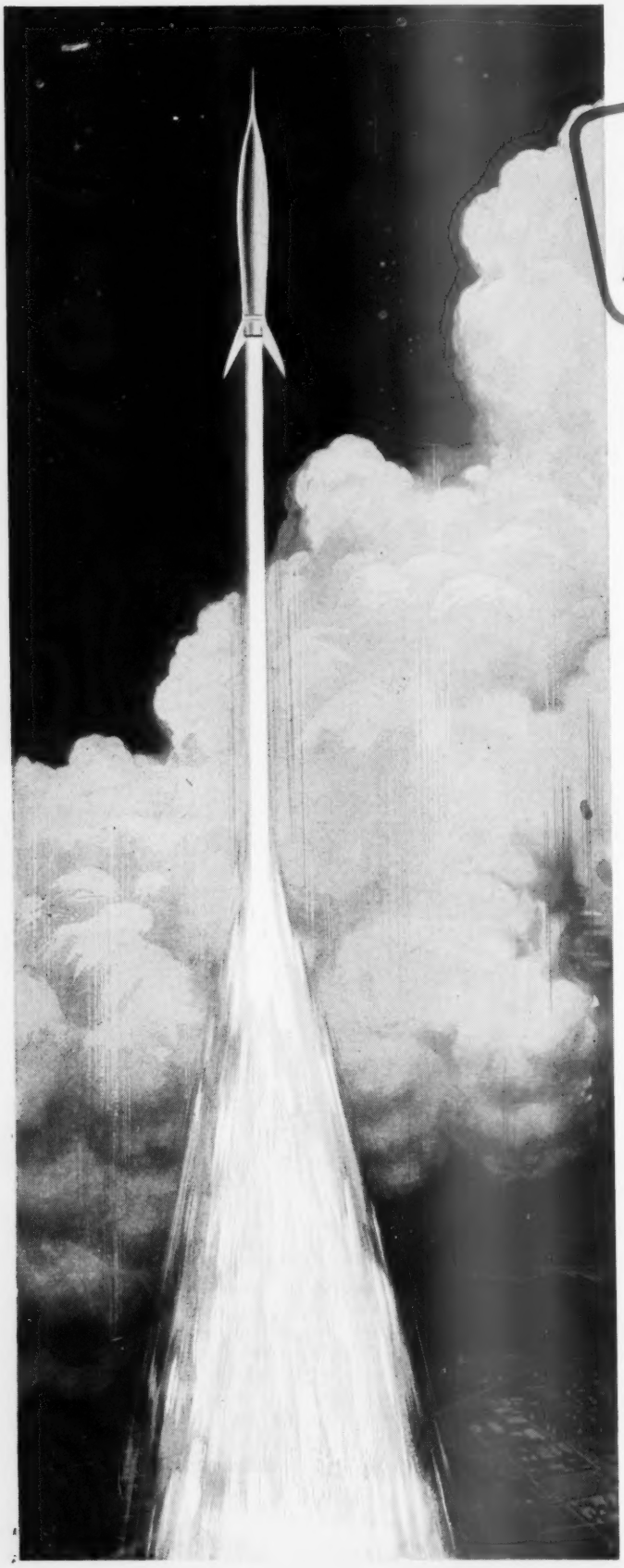

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Airplane Design (10)

Gadgets . . . Choke U.S. Air Power. Gilbert C. Close. *Aviation Age*, Vol. 17, No. 6, June, 1952, pp. 31, 32, illus. Analysis of the cost- and time-consuming factors introduced into aircraft design and production by unnecessarily complex gadgets and installations.

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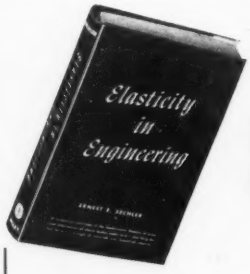

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Loads on Multi-Wheel Undercarriages During Ground Manoeuvring and Take-Off. J. W. Blinkhorn. *Royal Aeronautical Society, Journal*, Vol. 56, No. 499, July, 1952, pp. 547–556, illus.

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An Objective Type Method of Measuring Flight Performance; Development and Evaluation in the Naval Air Basic Training Command. W. R. Mahler. *Journal of Aviation Medicine*, Vol. 23, No. 3, June, 1952, pp. 259–262, 303.

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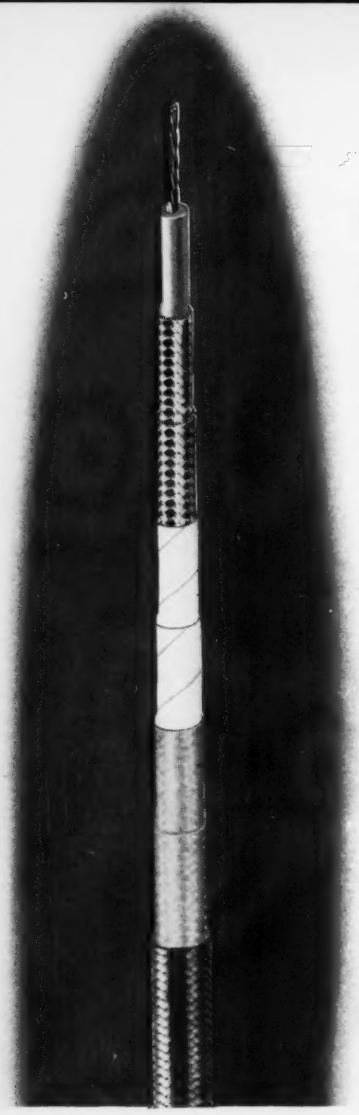

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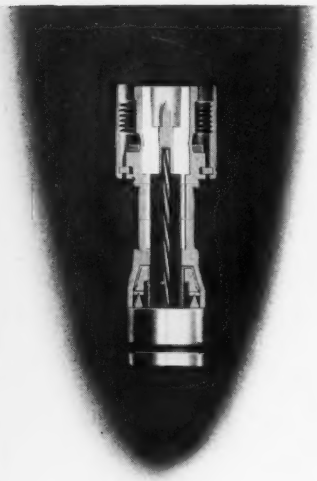

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Computers & Simulators

Static Magnetic Matrix Memory and Switching Circuits. Jan A. Rajchman. *RCA Review*, Vol. 13, No. 2, June, 1952, pp. 183–201, illus. 5 references.

Development of a memory system for digital computers and other information handling machines with an access time of several μsec. in which bits are stored in terms of the direction of magnetization of a multitude of saturated cores connected in a matrix array; construction and operation of a model with a capacity of 256 bits, developed to demonstrate principles of switching and operating schedules applicable to systems of any capacity.

Piezoelectric Transducers for Ultrasonic Delay Lines. H. N. Beveridge and W. W. Keith. *Institute of Radio Engineers, Proceedings*, Vol. 40, No. 7, July, 1952, pp. 828–835, illus. 8 references.

An analysis of the piezoelectric transducer as used in ultrasonic delay lines; application to the dynamic storage of wide-band intelligence such as the high-speed memory of digital computers.

Miniature Rectifier Computing and Controlling Circuits. An Wang. *Institute of Radio Engineers, Proceedings*, Vol. 40, No. 8, August, 1952, pp. 931–936, illus. 4 references.

Analysis of rectifier computing circuits using selenium-rectifier elements; development of techniques of circuit construction for a simple, compact, and economical rectifier system that is applicable to large-scale digital computers and complicated control systems.

Decision Elements. I, II. John D. Goodell. *Radio & Television News*, Vol. 48, Nos. 1, 2, July, August, 1952, *Radio-Electronic Engineering*, pp. 3–5, 14–16, 23, illus.

A theoretical solution for the control of obsolescence of digital computers in which decision elements—basic computing machine structures with one or more inputs and one or more outputs in which the outputs are defined by the character of the inputs—are defined and represented by matrices; application to various complete systems used in binary addition.

Network Synthesis by the Use of Potential Analogs. R. E. Scott. *Institute of Radio Engineers, Proceedings*, Vol. 40, No. 8, August, 1952, pp. 970–973, illus. 19 references.

Construction and operation of two analog devices for obtaining approximate forms of required insertion-loss or gain functions for network synthesis. The devices use a sheet of conducting Teledeltos paper to produce a two-dimensional potential field which simulates a required network.

Education & Training (38)

New Airline Boom in Flight Simulators. Philip Klass. *Aviation Week*, Vol. 57, No. 3, July 21, 1952, pp. 81, 82, illus Plans for increased production of flight simulators for multi-engined aircraft and for their increased use by airlines.

Electronics (3)

ANTENNAS

Self- and Mutual Impedances of Parallel Identical Antennas. Ronold King. *Institute of Radio Engineers, Proceedings*, Vol. 40, No. 8, August, 1952, pp. 981–988, illus. 15 references.

Development of a method for obtaining approximate second-order self- and mutual impedances of parallel identical antennas; extensive groups of curves of the impedances; comparison with experimental measurements and with available first-order or zeroth-order values.

Radiation Characteristics of Helical Antennas of Few Turns. Obed C. Haycock and James S. Ajioka. *Institute of Radio Engineers, Proceedings*. Vol. 40, No. 8, August, 1952, pp. 989–991, illus. 3 references.

Results of an investigation of helical antennas of few turns for ionosphere measurements at frequencies in the 3–8 mc. range; development of a method of producing circular polarization by resistance loading a $1^1/_4$-turn helix.

Cage-Type Very-High-Frequency Phase-Composition Omnidirectional Radio Range Antenna. F. J. Lundberg and F. X. Bucher. *Electrical Communication*, Vol. 29, No. 2, June, 1952, pp. 108–116, illus. Design, components, installation, and characteristics of the antenna.

The Absorption Gain and Back-Scattering Cross Section of the Cylindrical Antenna. S. H. Dike and D. D. King. *Institute of Radio Engineers, Proceedings*, Vol. 40, No. 7, July, 1952, pp. 853–860, illus. 14 references.

CIRCUITS & COMPONENTS

Network Synthesis Using Tchebycheff Polynomial Series. Sidney Darlington. *Bell System Technical Journal*, Vol. 31, No. 4, July, 1952, pp. 613–665, illus. 12 references.

Application to network synthesis technique of two Tchebycheff polynomial series that represent the assigned network characteristics and the approximating network function; specific examples.

The Response of RLC Resonant Circuits to EMF of Sawtooth Varying Frequency. Jean Marique. *Institute of Radio Engineers, Proceedings*, Vol. 40, No. 8, August, 1952, pp. 945–950, illus. 9 references.

Development of the mathematical solution for the response of an RLC series resonant circuit under the excitation of an e.m.f. that follows a sawtooth law for the case of spectrum analyzers and panoramic receivers in which exploration is continually repeated; analysis of the limits of the exploration.

A Note on the Reproduction of Pulses. David K. Cheng. *Institute of Radio Engineers, Proceedings*, Vol. 40, No. 8, August, 1952, pp. 962–965, illus. 1 reference. Analysis of the relative significance of rise time and percentage energy content in the reproduction of rectangular pulses.

An Optimization Theory of Time-Varying Linear Systems with Nonstationary Statistical Inputs. Richard C. Booton, Jr. *Institute of Radio Engineers, Proceedings*, Vol. 40, No. 8, August, 1952, pp. 977–981. 6 references.

Linear Circuit Theory and Servomechanism Design. Howard Hamer. *Electrical Engineering*, Vol. 71, No. 7, July, 1952, pp. 614, 615, illus. 4 references. Limitations of techniques based on linear circuit analysis for the design of servomechanisms.

Binary Counter Uses Two Transistors. Robert L. Trent. *Electronics*, Vol. 25, No. 7, July, 1952, pp. 100, 101, illus.

Development of a general-purpose binary counter with a repetition rate from 0 to 50 kc. which uses two transistors, has two stable d.c. equilibrium points, permits use of either positive or negative triggering pulses, and provides various timing and registry functions.

No Tubes Used in Heat-Control System. Philip Klass. *Aviation Week*, Vol. 57, No. 1, July 7, 1952, pp. 52, 54, 56, 58, illus.

Construction and operation of the Micropulse temperature control system developed by Barber-Colman Co. which uses no vacuum tubes and is in use with cockpit, cabin, and windshield heating systems of military aircraft. The system uses two small devices in place of electronic amplifiers—a micropositioner and a heater element that combine to provide signal pulses whose length and frequency vary with difference between actual and selected temperatures.

Heater-Voltage Compensation for Alternating-Current Amplifiers. N. W. Broten. *Institute of Radio Engineers, Proceedings*, Vol. 40, No. 7, July, 1952, pp. 843–845, illus. 8 references.

Circuit and operation of a feedback network for stabilizing tube characteristics and completely compensating for heater-voltage changes; comparison of experimental results for a 30-mc. compensated amplifier and a conventional 30-mc. amplifier.

A Broad-Band Interdigital Circuit for Use in Traveling-Wave-Type Amplifiers. R. C. Fletcher. *Institute of Radio Engineers, Proceedings*, Vol. 40, No. 8, August, 1952, pp. 951–958, illus. 5 references.

Distributed Amplifier Covers 10 to 360 Mc. Howard Scharfman. *Electronics*, Vol. 25, No. 7, July, 1952, pp. 113–115, illus. 3 references.

Development, construction, and operation of a distributed amplifier with a gain of 8 db. flat to ±2 db. over the 10 to 360-mc. band; application to millimicrosecond oscillography and intermediate and radio frequency amplification.

A Frequency Eliminating Transconductance Bridge. Walter C. Michels and Richard C. Barbera. *Review of Scientific Instruments*, Vol. 23, No. 6, June, 1952, pp. 293–295, illus. 3 references.

Development, circuit, and operation of a transconductance bridge (FETB) which requires no reference voltages and completely eliminates a single frequency component and suppresses in part a band of frequencies whose width may be varied within

wide limits by choice of circuit parameters; application to ripple elimination and to band elimination amplifiers.

Series Mode Crystal Oscillators; Circuit for Low-Activity Crystals. H. B. Dent. *Wireless World*, Vol. 58, No. 7, July, 1952, pp. 275–277, illus. 3 references.

A Wide-Range Oscillator in the Range from 8,000 to 15,000 MC. R. W. Wilmarth and J. L. Moll. *Institute of Radio Engineers, Proceedings*, Vol. 40, No. 7, July, 1952, pp. 813–817, illus. 2 references.

Construction and operation of a retarding field oscillator covering the range from 8,000 to 15,000 mc. and in which energy is taken from the tube by allowing the repeller, which is part of the resonant circuit, to radiate into a wave guide.

Note on Safe Resonator Current of Piezoelectric Elements. E. J. Post. *Institute of Radio Engineers, Proceedings*, Vol. 40, No. 7, July, 1952, p. 835. 5 references.

Carrier Concentrations and Fermi Levels in Semi-Conductors. J. S. Blakemore. *Electrical Communication*, Vol. 29, No. 2, June, 1952, pp. 131–153, illus. 23 references.

Development of the statistical theory of free carrier concentrations and the Fermi level of semiconductors over a wide range of conditions and using Fermi-Dirac statistics. The theory is given for an *n*-type semiconductor in which the current carriers are free electrons; the analysis, however, applied for a *p*-type semiconductor in which the current carriers are holes in an otherwise full band.

The ABC's of Germanium. J. P. Jordan. *Electrical Engineering*, Vol. 71, No. 7, July, 1952, pp. 619–625, illus.

The conduction mechanism and behavior of germanium in industrial applications; techniques of measuring the resistivity, Hall coefficient, thermoelectric power, and lifetime of germanium; *p-n* junction theory and its applications.

Single-Crystal Germanium. G. K. Teal, M. Sparks, and E. Buehler. *Institute of Radio Engineers, Proceedings*, Vol. 40, No. 8, August, 1952, pp. 906–912, illus. 12 references.

The ranges of properties and degree of compositional control are given for improved germanium single-crystals in which the behavior of the rectifying barriers between the *p*-type and *n*-type sections is predictable from the measured properties of each section; application to the *n-p-n* transistor.

Germanium Phenomenon. Alvin B. Kaufman. *Radio & Television News*, Vol. 48, No. 1, July, 1952, *Radio-Electronic Engineering*, pp. 10, 29, illus. A preliminary investigation of the increased forward resistance of germanium diodes when subjected to a magnetic field; possible applications.

COMMUNICATIONS

Basic Communication Theory. II—Autocorrelation and Cross-Correlation Functions. L. S. Schwartz. *Radio & Television News*, Vol. 48, No. 1, July, 1952, *Radio-Electronic Engineering*, pp. 11–13, illus. 9 references.

An analysis of random functions of time in relation to maintaining a continuous flow of information; development of a method of predicting such functions by use of statistical time series.

Efficient Coding. B. M. Oliver. *Bell System Technical Journal*, Vol. 31, No. 4, July, 1952, pp. 724–750, illus. 5 references.

Brief review of simpler aspects of communication theory, emphasizing the statistical encoding processes that require memory. Messages are converted to a reduced form by use of the Shannon-Fano code on a symbol-by-symbol basis.

CONSTRUCTION TECHNIQUES

Unitized Component Design. Charles H. Standish. *Radio & Television News*, Vol. 48, No. 1, July, 1952, *Radio-Electronic Engineering*, pp. 14–16, 28, illus.

Problems and costs of maintaining complex military electronic equipment; development and maintenance advantages of the unitized component design method in which equipment units are constructed as aggregations of compact plug-in assemblies; proposed extension and standardization of components designed by this method.

ELECTRONIC TUBES

Vacuum-Tube Analogy of Transistors. Hans E. Hollmann. *Electronics*, Vol. 25, No. 7, July, 1952, pp. 156, 158, 162, 164, 169, illus. 2 references.

Development, based on the duality principle, of an analogy between the retarding-field tube and the transistor; principles of operation of the retarding-field tube; applications to amplifier, oscillator, and transistor circuits.

An Experimental Study of Low-Power CW Magnetrons Having Few Segments. E. B. Callick. *Institute of Radio Engineers, Proceedings*, Vol. 40, No. 7, July, 1952, pp. 836–843, illus. 7 references.

An experimental study and comparison of the characteristics of multisegment magnetrons with those having two and four segments and of the relationship of these characteristics, particularly the size of the cathode relative to other dimensions of the tube, to variation in efficiency.

Frequency Control of Modulated Magnetrons by Resonant Injection System. L. L. Koros. *RCA Review*, Vol. 13, No. 1, March, 1952, pp. 47–57, illus. 4 references.

Results of an investigation in which U.H.F. or microwave crystal-controlled magnetron oscillators were used as r.f. power generators to produce amplitude- and angular-modulated high-power carriers with a frequency and phase stability that meets practical transmitter requirements.

A 7,000-Megacycle Developmental Magnetron for Frequency Modulation. H. K. Jenny. *RCA Review*, Vol. 13, No. 2, June, 1952, pp. 202–223, illus. 1 reference.

Design of a Low-Noise Pentode. P. Welch. *Electronics*, Vol. 25, No. 7, July, 1952, pp. 194, 196, 198, 200, 202, 204, illus.

Construction and operation of the 6BR7 tube that has a low anode-to-grid capacitance; design features that minimize microphony, hum, and hiss; application to the first stage of high-gain amplifiers and similar equipment using very low signal input levels.

A High-Voltage, Cold-Cathode Rectifier. E. G. Linder, J. H. Coleman, and E. G. Apgar. *Institute of Radio Engineers, Proceedings*, Vol. 40, No. 7, July, 1952, pp. 818–828, illus. 12 references.

Theory of operation and experimental data on a high-voltage cold-cathode rectifier, developed as part of a project on electron-trapping devices, for output voltages up to 14 kv. and currents up to one milliampere; advantages and application to voltage-multiplier rectifier circuits.

Studies of Externally Heated Hot Cathode Arcs. II—The Anode-Glow Mode. W. M. Webster, E. O. Johnson, L. Malter. *RCA Review*, Vol. 13, No. 2, June, 1952, pp. 163–182, illus. 3 references.

MEASUREMENTS & TESTING

Direct-Reading Frequency Measuring Equipment for the Range of 30 CPS to 30 MC. L. R. M. Vos de Wael. *Institute of Radio Engineers, Proceedings*, Vol. 40, No. 7, July, 1952, pp. 807–813, illus. 2 references.

Construction and operation of equipment that gives precise frequency measurements between 30 cycles per sec. and 30 mc. in one sec., which consists of an electronic counter ranging from 30 cycles per sec. ÷ 1 mc., an instrument giving multiples of 1 mc. in the range from 1 ÷ 29 mc., a combining part, and only one knob for choosing the desired multiple of 1 mc. The result of the measurement appears on the counter and on the knob.

A Guard Circuit for the Capacitance Bridge. *General Radio Experimenter*, Vol. 27, No. 3, August, 1952, pp. 1–5, illus.

Specification, operation, and performance of the Type 716-P4 Guard Circuit that provides a fifth point for the conventional four-arm bridge network of the Type 716-C Capacitance Bridge and makes it possible to measure the direct impedance between two points of a three-terminal network.

NAVIGATION AIDS

Airborne Receivers and Test Gear for Instrument Landing Systems. F. G. Overbury. *Electrical Communication*, Vol. 29, No. 2, June, 1952, pp. 122–130, illus. 1 reference.

Problems in the design of air-borne I.L.S. receivers; development and evaluation of the SR.14/15 receivers; instruments for bench and in-flight testing of equipment.

Facilitating Air-Traffic Control. *Flight*, Vol. 62, No. 2267, July 4, 1952, p. 13, illus. Equipment and layout of new control tower for Hawker Aircraft, Ltd.'s production flight testing at Dunsfold Airfield, England.

Navigational Aids at Dunsfold Airfield. *The Engineer*, Vol. 194, No. 5034, July 18, 1952, pp. 86, 87, illus. Construction and operation of radio and navigational equipment, including two V.H.F.-D.F. installations, of the new control tower at Dunsfold Airfield, England.

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RADAR

A New Airfield Radar. *The Aeroplane*, Vol. 83, No. 2140, July 25, 1952, p. 130, illus.

Construction and operation of the low-cost airfield radar, developed by Cossor Radar, Ltd., which is an accurate plan-projection indicator with an easily adjusted scanner, for short-range control of aircraft from take-off or for landing through 20 miles of cloud.

TRANSMISSION LINES

Generalized Telegraphist's Equations for Waveguides. S. A. Schelkunoff. *Bell System Technical Journal*, Vol. 31, No. 4, July, 1952, pp. 784–801, illus.

Maxwell's partial differential equations and boundary conditions for wave guides of constant cross section and conical horns of arbitrary shape filled with a heterogeneous and nonisotropic medium are converted into an infinite system of ordinary differential equations which represents a generalization of the telegraphist's equations from single-mode to multiple-mode transmission.

On the Excitation of Surface Waves. Georg Goubau. *Institute of Radio Engineers, Proceedings*, Vol. 40, No. 7, July, 1952, pp. 865–868, illus. 7 references. A mathematical proof of the existence of surface waves in the excitation of cylindrical surface wave guides.

Single- and Multi-Iris Resonant Structures. Irving Reingold, John L. Carter, and Kenton Garoff. *Institute of Radio Engineers, Proceedings*, Vol. 40, No. 7, July, 1952, pp. 861–865, illus. 2 references.

Experimental data on the characteristics of single- and multi-iris structures in a thin diaphragm that is placed transversely across a rectangular, standard *S*-band wave guide; their behavior as a function of position in the diaphram and the correlation between the single- and double-iris structures.

Surface Losses in Electromagnetic Cavity Resonators. I. Paghis. *Canadian Journal of Physics*, Vol. 30, No. 3, May, 1952, pp. 174–184, illus. 14 references.

An experimental investigation, using Southwell's relaxation method, of the relation between surface roughness and resonator losses, in which losses were determined by measuring the Q of a cylindrically symmetric brass electromagnetic cavity resonator, in the frequency range of 550—1,050 mc. per sec.

Symmetrically Placed Inductive Posts in Rectangular Wave Guide. H. Gruenberg. *Canadian Journal of Physics*, Vol. 30, No. 3, May, 1952, pp. 211–217, illus. 1 reference.

Derivation of a theoretical expression for the susceptance of two symmetrically placed inductance posts in a rectangular wave guide. Universal curves are presented which are valid for all rectangular guides in their normal operating range for different post diameters and offsets; comparison with results of experiments at 10.7, 4.74, and 3.20 cm. wave lengths.

Cutoff in Rectangular Wave Guides. *Radio & Television News*, Vol. 48, No. 1, July, 1952, Radio-Electronic Engineering, pp. 32, illus. Nomograph for determining the cutoff frequency of the $TM_{1,1}$ mode in rectangular wave guides up to 8 cm. in height when the dimensions of the guide are given.

Dominant Wave Transmission Characteristics of a Multimode Round Waveguide. A. P. King. *Institute of Radio Engineers, Proceedings*, Vol. 40, No. 8, August, 1952, pp. 966–969, illus. 2 references.

Analysis of the attenuation, return loss, effect of bowing on the line, and mode conversion effects on a straight run of round wave guides in the 4 kmc. range of frequencies.

A Precision Directional Coupler Using Multi-Hole Coupling. *Hewlett-Packard Journal*, Vol. 3, No. 7–8, March–April, 1952. 4 pp., illus.

Analysis of the mechanism of coupling; development of two new couplers of 10- and 20-db. values which consist of two waveguide sections that are bonded together and coupled by a series of round holes. The couplers are designed for the 8,200 to 12,400 mc. range to provide constant coupling over a wave-guide range of frequencies and to provide a high directivity of at least 40 db. even in couplers of 10 db.

Piezoelectric Transducers for Ultrasonic Delay Lines. H. N. Beveridge and W. W. Keith. *Institute of Radio Engineers, Proceedings*, Vol. 40, No. 7, July, 1952, pp. 828–835, illus. 8 references.

An analysis of the piezoelectric transducer as used in delay lines or similar ultrasonic devices; derivation of the overall frequency response and loss of a transducer from Roth's equivalent circuit; computation of the transient response of a delay line from an equivalent transmission-line circuit; comparison of the bandwidths and transient responses, measured on practical delay lines, with theoretical values.

Equipment

ELECTRIC (16)

Intermittent Faults in Aircraft Electric Systems. L. R. Larson, Mike Trbovich, and P. E. Toomire. *Electrical Engineering*, Vol. 71, No. 7, July, 1952, pp. 634–639, illus. 4 references.

An investigation in which intermittent faults were obtained in simulated 30-volt d.c., 120-volt d.c., and 120/208-volt 400-cycle a.c. electric systems to determine the approximate minimum fault current magnitude and duration; techniques of protecting against faults.

Generators and Alternators for Aircraft, Guided Missiles, Tanks and Ground Power. *Jack & Heintz, Inc., Technical Bulletin, File No. 1200*, 1952. 8 pp., illus., tables.

Flight Operating Problems (31)

ICE PREVENTION & REMOVAL

Spray Nozzles for the Simulation of Cloud Conditions in Icing Tests of Jet Engines. N. Golitzine, C. R. Sharp, and L. G. Badham. *Canada, National Aeronautical Establishment, Report No. 14*, 1951. 19 pp., illus. 6 references.

Methods and apparatus for testing pneumatic and swirl type spray nozzles for simulating natural cloud conditions data on the water droplet sizes obtainable in sprays from nozzles of different types under various icing conditions.

Flight Safety & Rescue (15)

Cockpit Design and Safety. William I. Stieglitz. *Aeronautical Engineering Review*, Vol. 11, No. 10, October, 1952, pp. 36–41, 124, illus. 27 references. Analysis of the probability of accidents due to pilot errors involving misinterpretation of instrument readings or mistakes in cockpit procedure.

Fire Detection in Non-Accessible Aircraft Baggage Compartments. R. W. J. Cockram. *Society of Licensed Aircraft Engineers, Journal*, Vol. 1, No. 5, May, 1952, pp. 3–8, 13, illus.

Methods of smoke- and fire-detection in aircraft baggage compartments that are not accessible in flight; development, construction, operation, and results of tests and service experience with the Pyrene Aircraft Smoke Detector; maintenance methods.

New Capsule for Highspeed Bailout. *Aviation Week*, Vol. 57, No. 4, July 28, 1952, p. 36, illus.

Construction, operation, and advantages of a rocket-propelled cockpit ejection capsule developed at Douglas Aircraft Co., Inc., for emergency bailout at supersonic speeds.

Fuels & Lubricants (12)

Testing Fuels and Lubricants in Modern Dynamometer Laboratory. *Automotive Industries*, Vol. 107, No. 2, July 15, 1952, pp. 50, 102, 105, 107, illus.

Facilities and equipment of the dynamometer laboratory constructed at the Esso Research Center of the Standard Oil Development Co. for testing the performance of fuels and lubricants under conditions similar to those found in actual use.

Effect of Initial Mixture Temperature on Flame Speed of Methane-Air, Propane-Air, and Ethylene-Air Mixtures. Gordon L. Dugger. (*U.S., N.A.C.A., Technical Notes Nos. 2170, 2374*, 1950.) *U.S., N.A.C.A., Report No. 1061*, 1952. 12 pp., illus. 29 references. Superintendent of Documents, Washington. $0.20.

The Effect of Surface Active Agents on Petroleum Fuels. F. G. Kitson. (*Canada, National Aeronautical Establishment, Laboratory Report No. LR-5*, July, 1951.) *Canada, National Aeronautical Establishment, Note No. 8*, 1952. 7 pp., illus. 10 references.

The Effect of Organic Additions on Ignition Velocity. II—Propane-Air Mixtures. D. B. Leason. *Australia, Department of Supply, Aeronautical Research Laboratories, Report No. E. 69*, May, 1952. 21 pp., illus. 41 references.

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Gliders (35)

On the Possibility of Soaring on Traveling Waves in the Jetstream. Joachim Kuettner. *Soaring*, Vol. 16, No. 3, May-June, 1952, pp. 9–14, illus.

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New AF Gyro Gets Avionics Assist. Philip Klass. *Aviation Week*, Vol. 57, No. 2, July, 14, 1952, pp. 52, 54, 56, 57, illus.

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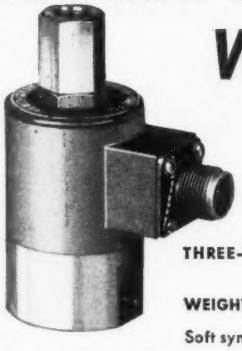

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Early Units of Measurement and the Nautical Mile. Alton B. Moody. *Institute of Navigation, Journal*, Vol. 5, No. 3, July, 1952, pp. 262–270.

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Details of U.S.S.R. intermediate and heavy caliber aircraft guns and of the ammunition used for the various models; explanation of the code used for marking ammunition chests and guns.

Photography (26)

Reliability of Photoelectric Photometry. N. T. Gridgeman. *Analytical Chemistry*, Vol. 24, No. 3, March, 1952, pp. 445–449, illus. 17 references. Review of the theory of the precision of photoelectric photometry; error sources; statistical analysis of error distribution and of precision.

Power Plants

JET & TURBINE (5)

Combustion Problems in the Gas Turbine. M. S. Kuhring. *Canada, National Aeronautical Establishment, Aeronautical Laboratories, Quarterly Bulletin, Report No. NAE 1952 (2)*, April 1–June 30, 1952, pp. 1–6, illus.

Fundamentals of the combustion process in gas turbines; problems and techniques of obtaining high combustion efficiencies; combustion-chamber design; selection of the optimum fuel and the optimum fuel-air ratio.

Effect of Compressor-Outlet Air Bleed on Performance of a Centrifugal-Flow Turbojet Engine with a Constant-Area Jet Nozzle. Sidney C. Huntley. *U.S., N.A.C.A., Technical Note No. 2713*, June, 1952. 20 pp., illus. 4 references.

The Bristol Olympus Turbo-Jet. *The Engineer*, Vol. 194, No. 5032, July 4, 1952, pp. 24, 25, illus.

Development, construction, and performance of the Bristol Olympus turbojet engine that weighs 3,520 lbs., has a diameter of 40 in., a length of 124 in. from intake to exhaust flange, and a specific fuel consumption of 0.766 lb. per lb. thrust per hr., and develops nearly 10,000 lbs. static thrust and 9,750 lbs. maximum thrust.

A Close Look at Bristol Olympus. *Aviation Week*, Vol. 57, No. 3, July 21, 1952, pp. 44, 45, illus. Design and performance of the Bristol Olympus turbojet engine; comparison with the Pratt & Whitney J-57.

Bristol's Olympus—A New Jet Turbine. *The Aeroplane*, Vol. 83, No. 2137, July 4, 1952, illus. Development, construction, and operation.

Olympus. *Flight*, Vol. 62, No. 2267, July 4, 1952, pp. 2, 3, illus. Development, construction, and operation of the Bristol Olympus axial-flow turbojet engine.

Development of the Ghost Jet Engine for Airliner Propulsion. John Brodie. *de Havilland Gazette*, No. 69, June, 1952, pp. 81–85, illus.

Hispano-Suiza Jet Engine Performs Well in Tests. W. F. Bradley. *Automotive Industries*, Vol. 107, No. 1, July 1, 1952, pp. 54, 55, illus.

Results of two official tests, one of 150 hours duration under standard French testing conditions, the other of $6\frac{1}{2}$ hours under standard British conditions, in which the R-300 H.S., a modification of the Rolls-Royce Nene jet engine built by Hispano-Suiza Co., produced a static thrust of 5,940 lbs. and an uncorrected thrust of 6,380 lbs.

Armstrong Siddeley Mamba (Aviation Design Progress). Randolph Hawthorne. *Aviation Age*, Vol. 17, No. 6, June, 1952, pp. 36, 37, illus.

Design and performance of the Armstrong Siddeley Mamba and Double Mamba axial-flow turboprop engines that are being produced under license in the U.S. by Curtiss-Wright Corp.

Latest British Proteus Propeller Turbine Engine. *Automotive Industries*, Vol. 107, No. 2, July 15, 1952, pp. 38, 39, 114, illus., cutaway drawings.

Design features and improvements that have resulted in increased overall performance and reduced weight and length of the Bristol Proteus III (700 series) turboprop engine.

Redesigned Proteus Has Better Economy. David A. Anderton. *Aviation Week*, Vol. 57, No. 2, July 14, 1952, pp. 22, 23, 25, 28, 30, illus., cutaway drawing.

Construction, operation, and results of test runs on the Bristol Mk. 705 Proteus III reverse-flow turboprop engine that has 12 stages of axial compression followed by a single stage of centrifugal compression.

Liquid-Coupled Regenerators for Turboprops. A. L. London and W. M. Kays. *Aeronautical Engineering Review*, Vol. 11, No. 10, October, 1952, pp. 42–53, 124, illus. 10 references.

Cycle studies on a low-pressure regenerator-turboprop engine; design studies on a liquid-coupled indirect-transfer regenerator that consists of two heat exchangers coupled by a suitable liquid heat-transfer medium.

Bristol Phoebus Research Engine. Paul H. Wilkinson. *Aviation Age*, Vol. 17, No. 6, June, 1952, pp. 38, 39, illus.

Design and construction of the Bristol Phoebus full-scale turbojet engine that is equipped with a single-stage centrifugal-flow compressor in addition to an axial-flow compressor; role of the Phoebus in the development of the Bristol Proteus axial-flow turboprop.

Spray Nozzles for the Simulation of Cloud Conditions in Icing Tests of Jet Engines. N. Golitzine, C. R. Sharp, and L. G. Badham. *Canada, National Aeronautical Establishment, Report No. 14*, 1951. 19 pp., illus. 6 references.

RAM-JET & PULSE-JET

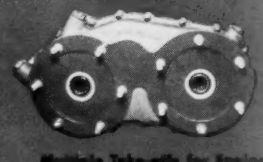
The Shock Ignition Engine. Frank F. Rand, Jr. *Aeronautical Engineering Review*, Vol. 11, No. 10, October, 1952, pp. 22–27, 62, illus. Theory of shock ignition in a simple steady flow cycle; application of shock ignition to principles the design of a ram-jet engine.

RECIPROCATING (6)

Wind-Tunnel Tests on the Spoiling Effects of Engine Cooling Gills on Radial Air-Cooled Installations on a Wing. J. Seddon and J. A. Kirk. *Gt. Brit., Aeronautical Research Council, Reports and Memoranda No. 2558*, 1952 (January, 1942). 26 pp., illus. 8 references. British Information Services, New York. $1.70.

IN-FLIGHT EQUIPMENT

ACCESSORY DRIVES



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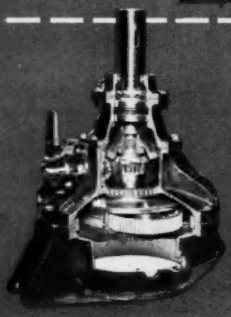
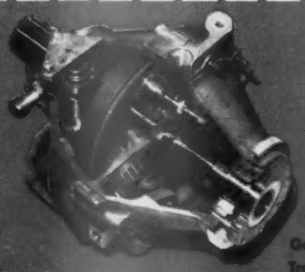


Helicopter Transmission



Gas Turbine Transmission

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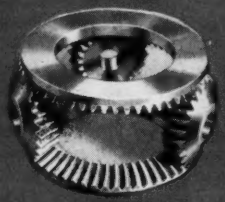

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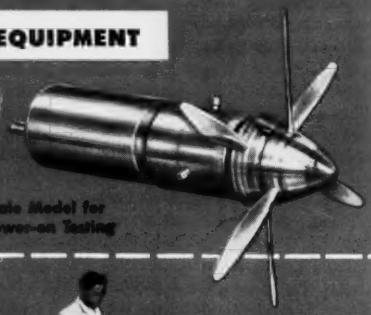

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High-Speed Test Equipment

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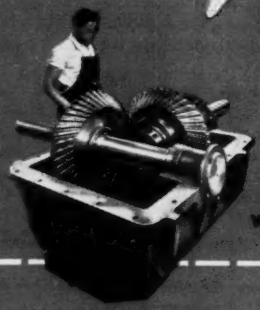

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Summary of Investigation of Two-Stroke-Cycle Gas-Generator Aircraft Engine. B. I. Sather, F. R. Schuricht, and A. E. Biermann. *American Society of Mechanical Engineers, Transactions*, Vol. 74, No. 5, July, 1952, pp. 637–653, illus. 20 references.

Theoretical analysis of the ideal gas-generator engine and an analysis of methods of achieving the ideal performance when the engine components are specified; results of experiments performed on the reciprocating components of three types of two-stroke-cycle single-cylinder test engines operating at gas-generator pressure and temperature levels.

Arctic Oil System. Robert J. Reed. *Aviation Age*, Vol. 17, No. 6, June, 1952, p. 33, illus.

Construction and operation of an automatic oil system that incorporates a diverter-segregator valve and completely isolates a limited quantity of oil that can be diluted sufficiently to flow and permit takeoffs in 20 min. following prolonged exposure at temperatures down to −65°F. The system was developed by United Aircraft Products, Inc., and is in production for the Grumman SA-16 and the Piasecki H-21 A and B.

ROCKETS (4)

Snarler. *Flight*, Vol. 62, No. 2270, July 25, 1952, pp. 92, 93, illus.

Construction of the Armstrong Siddeley Snarler liquid-fuel (oxygen and water-methanol) rocket-motor of 2,000 lbs. thrust; handling techniques for liquid oxygen; possible substitution of kerosene for water-methanol.

Production (36)

Moving the Production Line. *Aviation Age*, Vol. 17, No. 6, June, 1952, pp. 43–45, illus. Equipment and techniques used to expedite handling of materials and assemblies in aircraft manufacture.

New Components for Airframe Construction; Report of Progress. John F. Faulkner and John H. Alden. *Aeronautical Engineering Review*, Vol. 11, No. 10, October, 1952, pp. 28–35, illus.

Metal Bonding; Developments in the Redux Process; Application of the Vacuum Technique. G. S. Newell. *Aircraft Production*, Vol. 14, No. 165, July, 1952, pp. 220–223, illus. 17 references.

Shell Mold Process Casts Stainless. Irving Stone. *Aviation Week*, Vol. 57, No. 2, July 14, 1952, pp. 33, 34, 36, 38, 41, illus.

Advantages of and application to the molding of stainless steel of the shell-mold process in which the molten metal is poured into thin bonded sand-and-resin shells instead of the conventional heavy sand molds.

Turbine and Compressor Blade Manufacture. H. G. Herrington. *Metal Treatment*, Vol. 19, No. 80, May, 1952, pp. 225–228, illus. A comparison of the metals and drop forging and pressing techniques for the manufacture of compressor blades in Great Britain and the U.S.

American and British Methods. H. G. Herrington. *Hawker Siddeley Review*, Vol. 5, No. 2, June, 1952, pp. 31–33, illus. Comparison of British and American methods and materials used for the production of forged, stamped, or pressed turbine and compressor blades.

Upset Blades. *Aircraft Production*, Vol. 14, No. 165, July, 1952, pp. 227–229, illus.

Equipment and methods used in the electro-upset forging process developed by Omes Ltd.; application to the production of gas-turbine rotor and stator blades.

Application of Electric Upset Forging; Use in Jet Engine Blade Production. Paul Granby. *Steel Processing*, Vol. 38, No. 5, May, 1952, pp. 228–231, 243, illus.

Metal Cutting Temperatures and Tool Wear. I. A. O. Schmidt. *Tool Engineer*, Vol. 29, No. 1, July, 1952, pp. 33–35, illus.

Vampire Canopy. II—Machining Processes on Unit Castings; Starboard Windscreen; Side Window and Hatch. *Aircraft Production*, Vol. 14, No. 165, July, 1952, pp. 240–243, illus.

An Analysis of Cost Estimating Principles and Practices. III. Lawrence E. Doyle. *Tool Engineer*, Vol. 29, No. 1, July, 1952, pp. 55–58, illus.

Producing the (Boulton Paul) Balliol T.Mk. 2. *The Aeroplane*, Vol. 83, No. 2139, July 18, 1952, pp. 98, 99, illus.

High-Pressure Rubber-Die Forming. *Aircraft Production*, Vol. 14, No 165, July, 1952, pp. 224–226, illus. Construction and operation of the Wheelon direct-acting hydraulic press for forming rubber dies which operates at 5,000 lbs. per sq.in.

Heavy Press Program Takes a Big Step. *Aviation Week*, Vol. 57, No. 3, July 21, 1952, pp. 38, 40, 42, illus.

Casting equipment and techniques for producing a crack-free 32-in.-diameter 75S ingot developed by Kaiser Aluminum & Chemical Corp. for the U.S.A.F. heavy forge press program.

USAF Puts Its Money on "Big Squeeze." Irving Stone. *Aviation Week*, Vol. 57, No. 1, July 7, 1952, pp. 38, 40, 42, 46, illus. U.S.A.F. program for the building of 17 forge presses up to 50,000 tons for aircraft production.

Design of Forging Machine Tools. E. W. Mace. *Metal Treatment*, Vol. 19, No. 81, June, 1952, pp. 263, 264, 274, illus.

Some Factors Affecting Wear on Cemented Carbide Tools. E. M. Trent. *Institution of Mechanical Engineers, Proceedings (A)*, Vol. 166, No.1, 1952, pp. 64–70, Discussion, pp. 70–74, illus. 8 references.

Specialty Die Designs for Stamping and Forming. III—The Sol-A-Die Process. Lester F. Spencer. *Steel Processing*, Vol. 38, No. 5, May, 1952, pp. 234–238, 257, illus. 3 references.

Techniques used with the Sol-A-Die process developed by the Solar Aircraft Co. for forming small quantities of complex and irregular sheet metal parts for aircraft use.

Tool Requirements of Tougher Alloys. P. G. DeHuff and D. C. Goldberg. *Aviation Age*, Vol. 17, No. 6, June, 1952, pp. 6–15, illus. Factors in the selection of tool design and machining techniques for optimum efficiency in producing jet-engine parts from high-temperature alloys.

Reference Works (47)

A Review of Certain Analysis Methods for Swept-Wing Structures. M. L. Williams. *Journal of the Aeronautical Sciences*, Vol. 19, No. 9, September, 1952, pp. 615–629, illus. 65 references.

Static analysis methods for swept-wing structures; list of references covering the period from 1946 to 1951 is classified under two headings—stiffened sheet construction and solid and thick-walled construction.

A Dictionary of Metallurgy. V, VI. A. D. Merriman and J. S. Bowden. *Metal Treatment*, Vol. 19, Nos. 80, 81, May, June, 1952, pp. 217–224; 265–272, illus.

Air Lines of the World. *The Aeroplane*, Vol. 83, No. 2138, July 11, 1952, pp. 47–76, illus.

An alphabetically arranged directory of air-line companies of the world, grouped first by continents and then by countries, listing their corporate names, headquarters, facilities, fleet composition, personnel, and brief reviews of their development; a table gives statistics on fleet composition and operations, as of December 31, 1951.

Rotating Wing Aircraft (34)

American Helicopter XA-5 Pulse-Jet-Powered Two-Place Helicopter. Lewis Emmerich and Douglas B. Darling. *CEC Recordings*, Vol. 6, No. 2, June, 1952, pp. 5–7, illus.

Comparison of the performance of helicopters that have rotor-tip jet power plants with conventionally-powered helicopters; details of the in-flight test program for the XA-5.

Bristol Type 171 Mk.3 Single-Rotor and Type 173 Twin-Rotor Helicopters, England. *Flight*, Vol. 62, No. 2267, July 4, 1952, pp. 16–19, illus.

Bristol Type 171 Sycamore Mk. 10 Ambulance Helicopter, England. *Indian Skyways*, Vol. 6, No. 4, April, 1952, pp. 36, 37, illus.

Jacobs Model 104 Single-Rotor Five-Place Helicopter. *Automotive Industries*, Vol. 107, No. 2, July 15, 1952, pp. 42, 43, illus.

Piasecki YH-21 Work-Horse Twin-Rotor Helicopter. *Aviation Week*, Vol. 57, No. 3, July 21, 1952, pp. 22–24, 28, 31, 32, illus. Built-in work platforms and other design features that permit systems servicing, engine checks and maintenance, and rotor and hub overhaul during field operations.

Sciences, General (33)

MATHEMATICS

End Corrections for Frequency Response Obtained by Laplace Transformations. G. M. Andrew. *U.S., Air Force, Flight Test Center, Edwards A.F.B., Calif., Report No. AFFTC 52-15,* February 7, 1952. 30 pp., illus. 4 references.

Development, using the Laplace transform, of formulas for the end correction of frequency response for step, ramp, and damped sine curves. The appendixes give the development of the end corrections by classical methods.

Escalator Methods for Latent Roots. L. Fox. *Quarterly Journal of Mechanics and Applied Mathematics,* Vol. 5, Part 2, June, 1952, pp. 178–190. 2 references. The theory of the general escalator processes, both forward and backward, is established by the use of the properties of partitioned matrices.

Alternative Derivations of Fox's Escalator Formulae for Latent Roots. George E. Forsythe. *Quarterly Journal of Mechanics and Applied Mathematics,* Vol. 5, Part 2, June, 1952, pp. 191–195. 3 references.

PHYSICS

Extension of the Carbon 14 Age Method. J. Laurence Kulp and Lansing E. Tryon. *Review of Scientific Instruments,* Vol. 23, No. 6, June, 1952, pp. 296, 297, illus. 5 references.

Development of a method of extending routine carbon 14 age measurements from 25,000 to 30,000 years which uses modified cosmic-ray counters for reduction of the background-to-sample ratio.

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Interstellar Flight. L. R. Shepherd. *British Interplanetary Society, Journal,* Vol. 11, No. 4, July, 1952, pp. 149–167, illus. 6 references.

An analysis of the factors of distance, time, and energy in relation to the achievement of flight to the nearest stars over a period of centuries by a vehicle deriving its power from known nuclear reactions that allow velocities of 5,000 to 10,000 km. per sec.; application of the equations of relativistic dynamics developed in Einstein's special theory of relativity to the achievement of velocities close to that of light; effects of the collision of interstellar matter with vehicles propelled at near optic velocities.

Interorbital Transport Techniques (with Special Reference to Solar Derived Power). H. Preston-Thomas. *British Interplanetary Society, Journal,* Vol. 11, No. 4, July, 1952, pp. 173–193, illus. 15 references.

Development of general design data and details of various drive systems for spaceships that operate from a manned satellite station and collect raw materials from other stars and return them to earth; methods of converting solar radiation to electric power; comparison of the solar power system with an indirect atomic system.

Structures (7)

Errors in Stress Determination at the Free Boundaries of Frozen Stress Photoelastic Models. V. M. Hickson. *British Journal of Applied Physics,* Vol. 3, No. 6, June, 1952, pp. 176–181, illus. 4 references.

Approximate calculation of the errors in stress determination at the free boundaries of frozen stress photoelastic models which are due to measurement techniques and to the use of slices of finite thickness.

Readers' Forum: The Prandtl Membrane Analogy for Temperature Fields with Permanent Heat Sources or Sinks. Paul J. Schneider. *Journal of the Aeronautical Sciences,* Vol. 19, No. 9, September, 1952, pp. 644, 645, illus. 3 references.

Outline of the theory and mechanics of the Prandtl membrane analogy; extension to experimental solutions for steady-state two-dimensional temperature distributions with permanent heat sources or sinks, including cases of nonregular boundary shape.

Plastic Flexure of Mild Steel Beams of Rectangular Cross-Section. K. K. Schackell and J. H. Welsh. *Institution of Mechanical Engineers, Proceedings (A),* Vol. 166, No. 1, 1952, pp. 112–119, Discussion, pp. 119–122, illus. 7 references.

Results of tension, compression, and flexure tests undertaken to determine the shape of the stress-strain curve immediately after the initial yielding and the suitability of using the upper yield stress as a design criterion in such cases as flexure; 0.28 per cent carbon steel beams of rectangular cross section under a maximum strain of about three times that of the initial yield were used.

The Stability of the Compression Cover of Box Beams Stiffened by Posts. Paul Seide and Paul F. Barrett. (*U.S., N.A.C.A., Technical Note No. 2153,* 1950.) *U.S., N.A.C.A., Report No. 1047,* 1951. 16 pp., illus. 7 references. Superintendent of Documents, Washington. $0.20.

Stress Distribution Near a Rectangular Cut-Out in a Reinforced Circular Cylinder Due to Direct Shear Loading and Torque. I—Test Results. G. Henson. *College of Aeronautics, Cranfield, England, Report No. 51,* January, 1952. 25 pp., illus. 15 references. 5*s*.

Buckling of Thin-Walled Cylinder Under Axial Compression and Internal Pressure. Hsu Lo, Harold Crate, and Edward B. Schwartz. (*U.S., N.A.C.A., Technical Note No. 2021,* 1950.) *U.S., N.A.C.A., Report No. 1027,* 1951. 9 pp., illus. 8 references. Superintendent of Documents, Washington. $0.15.

Uniqueness Theorems of Two-Dimensional Elasticity Theory. R. Tiffen. *Quarterly Journal of Mechanics and Applied Mathematics,* Vol. 5, Part 2, June, 1952, pp. 237–252, illus. 10 references.

Development of uniqueness theorems for elastic material occupying a multiply connected region and in a state of plane strain or generalized plane stress; analysis of two- and three-dimensional cases with finite, finite and infinite, and infinite boundary conditions.

The Stability of a Compressed Elastic Ring and of a Flexible Heavy Structure Spread by a System of Elastic Rings. G. W. H. Stevens. *Quarterly Journal of Mechanics and Applied Mathematics,* Vol. 5, Part 2, June, 1952, pp. 221–236, illus. 9 references.

Calculation of the Stresses of the Orthotropic Strip with a Hole. Masakazu Higuchi. *Kyushu, Imperial University, Research Institute for Applied Mechanics, Reports,* Vol. 1, No. 1, January, 1952, pp. 33–45, illus. 7 references. Calculations of the stresses of the orthotropic strip with a hole using a stress function of a type similar to Airy stress function.

Determination of Principal Plastic Strains. W. E. Cooper. *American Society of Mechanical Engineers, Transactions,* Vol. 74, No. 5, July, 1952, pp. 821–824, illus. 11 references.

Techniques for extending the grid method of plastic-strain determination to include the determination of the strain at a point, rather than over a finite gage length, and of the principal strain, magnitude, and direction when these directions are not necessarily in alignment with the original grid.

The Bending and Twisting of Anisotropic Plates. R. F. S. Hearmon and E. H. Adams. *British Journal of Applied Physics,* Vol. 3, No. 5, May, 1952, pp. 150–156, illus. 7 references.

Summary of the theory of the deflection of anisotropic plates under bending and twisting loads; comparison of observed with calculated behavior in which plywood was used as the experimental material.

Bending of a Thin Elliptic Plate of an Orthotropic Material Under Uniform Lateral Load. Yosio Ōhasi. *Zeitschrift für angewandte Mathematik und Physik,* Vol. 3, No. 3, May 15, 1952, pp. 212–224, illus. 3 references.

Fatigue Tests on Typical Two Spar Light Alloy Structures (Meteor 4 Tailplanes) Under Reversed Loading. K. D. Raithby. *Gt. Brit., Aeronautical Research Council, Current Papers No. 88,* 1952 (May, 1951). 24 pp., illus. 2 references. British Information Services, New York. $1.00.

A Boundary Problem in Orthotropic Generalized Plane Stress. Kathleen M. Stephens. *Quarterly Journal of Mechanics and Applied Mathematics,* Vol. 5, Part 2, June, 1952, pp. 206–220, illus. 3 references.

Development of a first approach to the solution of boundary-value problems in aeolotropic plates; analysis of the effects of a curvilinear triangular hole in aeolotropic plates with otherwise undisturbed stress conditions.

Elastic Stability of the Square Plate with a Central Circular Hole Under Edge Thrust. Toyoji Kumai. *Kyushu, Imperial University, Research Institute for Applied Mechanics, Reports,* Vol. 1, No. 2, April, 1952, pp. 1–10, illus. 5 references.

Structural Aspects of Suction Wings. E. H. Mansfield. *Gt. Brit., Aeronautical Research Council, Current Papers No. 87*, 1952 (June, 1951). 25 pp., illus. British Information Services, New York. $1.15.

Consideration of structural design problems and weight penalties in the use of distributed wing suction; analysis of two general types of construction, suction-duct sizes, added power requirements, porous materials, and the loading on porous surfaces.

A Review of Certain Analysis Methods for Swept-Wing Structures. M. L. Williams. *Journal of the Aeronautical Sciences*, Vol. 19, No. 9, September, 1952, pp. 615–629, illus. 65 references.

Consideration of static analysis methods with regard to stresses and deflections in stiffened-sheet, solid, and thick-walled shell structures types of wing construction; bibliography covers swept-wing literature from 1946 to 1951.

Readers' Forum: Comments on "Remarks on Dynamic Loads in Landing" by A. Zahorski. H. Norman Abramson. *Journal of the Aeronautical Sciences*, Vol. 19, No. 9, September, 1952, p. 639. 11 references.

Thermodynamics (18)

A Biharmonic Relaxation Method for Calculating Thermal Stress in Cooled Irregular Cylinders. Arthur G. Holms. (*U.S., N.A.C.A., Technical Note No. 2434*, 1951.) *U.S., N.A.C.A., Report No. 1059*, 1952. 19 pp., illus. 14 references. Superintendent of Documents, Washington. $0.25.

Review of Optimum Design of Gas-Turbine Regenerators. D. Aronson. *American Society of Mechanical Engineers, Transactions*, Vol. 74, No. 5, July, 1952, pp. 675–681, Discussion, pp. 681–683, illus. 12 references.

A comparison of several types of heat-transfer surfaces or arrangements for gas-turbine regenerators and an analysis of the optimum relationships applicable to each type; an outline of the distinctive features of bare-tube and extended-surface design.

Liquid-Coupled Regenerators for Turboprops. A. L. London and W. M. Kays. *Aeronautical Engineering Review*, Vol. 11, No. 10, October, 1952, pp. 42–53, 124, illus. 10 references.

Cycle studies on a low-pressure regenerator-turboprop engine; design studies on a liquid-coupled indirect-transfer regenerator that consists of two heat exchangers coupled by a suitable liquid heat-transfer medium.

Measurements of Average Heat-Transfer and Friction Coefficients for Subsonic Flow of Air in Smooth Tubes at High Surface and Fluid Temperatures. Leroy V. Humble, Warren H. Lowdermilk, and Leland G. Desmon (*U.S., N.A.C.A., Research Memorandum Nos. E7L31, E8L03, E50E23, and E50H23*, 1948–1950.) *U.S., N.A.C.A. Report No. 1020*, 1951. 15 pp., illus. 13 references. Superintendent of Documents, Washington. $0.20.

Readers' Forum: Note on the Calculation of Transport Properties of Gas Mixtures. Eldon L. Knuth. *Journal of the Aeronautical Sciences*, Vol. 19, No. 9, September, 1952, p. 644, illus. 4 references.

Water-Borne Aircraft (21)

Short S-35 Shetland 1 Four-Engined Flying Boat, England. (Tank Tests on the Effect of Slipstream on the Water Performance of a Large Four-Engined Flying Boat). S. Raymond. *Gt. Brit., Aeronautical Research Council, Current Papers No. 6*, 1950 (April, 1945). 39 pp., illus., folding charts. 7 references. British Information Services, New York. $0.65.

Tests, undertaken as part of an investigation of the difference between model and full-scale results, in the R.A.E. towing tank of the effects of slipstream, degree of initial disturbance, and method of towing the model on porpoising stability, trim, and spray of a large four-engined flying boat; correlation with available full-scale evidence.

Wind Tunnels & Research Facilities

Current Projects in Aerodynamics Laboratory, Aircraft and Allied Instrument Laboratory, Engine Laboratory, Engineering Section, Flight Research Section, Fuels and Lubricants Laboratory, Gas Dynamics Section, Low Temperature Laboratory, and Structures Laboratory. *Canada, National Research Council, Aeronautical Laboratories, Quarterly Bulletin, Report No. NAE 1952 (2)*, April 1–June 30, 1952, pp. 7–30, illus.

Testing Fuels and Lubricants in Modern Dynamometer Laboratory. *Automotive Industries*, Vol. 107, No. 2, July 15, 1952, pp. 50, 102, 105, 107, illus.

Facilities and equipment of the dynamometer laboratory constructed at the Esso Research Center of the Standard Oil Development Co. for testing the performance of fuels and lubricants under conditions similar to those found in actual use.

R.C.A.F. Research and Development. J. J. Green. *Engineering Journal*, Vol. 35, No. 6, June, 1952, pp. 615–620. Summary of the development of air research in Canada over the past 30 years; outline of postwar research facilities and projects.

Investigation into the Operating Cycles of a Two-Dimensional Supersonic Wind Tunnel. G. V. Bull. (*Toronto, University, Ph.D. Thesis.*) *Journal of the Aeronautical Sciences*, Vol. 19, No. 9, September, 1952, pp. 609–614, illus. 8 references.

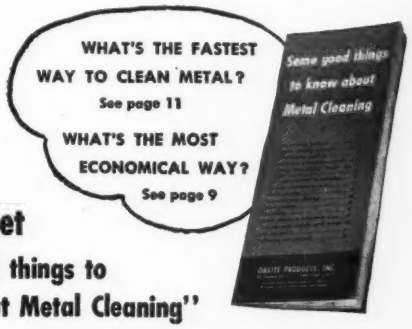
Tunnelwall Interference for Aerofoils and Aerofoil-Fuselage Combinations in a Tunnel with an Octagonal Section for Incompressible Flow. H. G. Loos. *Netherlands, Nationaal Luchtvaartlaboratorium, Amsterdam, Report No. A.1204* (*Reports and Transactions*, Vol. 16, pp. A19–A27), 1951. 9 pp., illus. 3 references.

Calculation of the interference between tip vortices and the walls of an octagonal tunnel by replacing the oblique walls with suitable chosen quadruples; computation of the interaction of a cylindrical fuselage, an airfoil, and the tunnel walls using an approximate image method.

Note on Wall Interference in Two-Dimensional Flow at Subsonic and Transonic Speeds. G. Drougge. *Sweden, Flygtekniska Försöksanstalt, Meddelande Nr. 40*, 1951. 14 pp., illus. 5 references. Teknicka Högskolans Rotaprinttryckeri, Stockholm, Kr. 1:50.

Analysis, using a linear approximation of the Mach Number across the wind-tunnel test section, of Mach Number wind-tunnel correction factors; analysis of reflection from the tunnel walls and from the model.

Short S-35 Shetland 1 Four-Engined Flying Boat, England (Tank Tests on the Effect of Slipstream on the Water Performance of a Large Four-Engined Flying Boat). S. Raymond. *Gt. Brit., Aeronautical Research Council, Current Papers No. 6,*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1950 (April, 1945). 39 pp., illus., folding charts. 7 references. British Information Services, New York. $0.65.

Tests, undertaken as part of an investigation of the difference between model and full-scale results, in the R.A.E. towing tank of the effects of slipstream, degree of initial disturbance, and method of towing the model on porpoising stability, trim, and spray of a large four-engined flying boat; correlation with available full-scale evidence.

High-Speed Cascade Testing Techniques. F. H. Keast. *American Society of Mechanical Engineers, Transactions*, Vol. 74, No. 5, July, 1952, pp. 685–693, Discussion, pp. 691–693, illus. 6 references.

Construction and operation of a cascade wind tunnel with auxiliary automatic transverse and recording gear and a wedge-shaped probe; development of an analytic method for turbine cascades which converts cascade results into a turbine-performance chart and yields a critical load factor.

Boundary Layer Measurements in the UTIA 5- by 7-Inch Supersonic Wind Tunnel. J. Ruptash. *Toronto, University, Institute of Aerophysics, Report No. 16*, May, 1952. 46 pp., illus. 14 references.

Design details of the UTIA 5- by 7-in. intermittent-flow supersonic wind tunnel; instrumentation for measuring the boundary-layer thicknesses in the nozzle and at the corners of the channel.

Flutter Analysis of Complex Airplanes by Experimental Methods. E. Berkeley Kinnaman. *Journal of the Aeronautical Sciences*, Vol. 19, No. 9, September, 1952, pp. 577–584, illus.

Analysis, using a mechanical analog or wind-tunnel model, of a highly elastic airplane with a sweptback wing of high aspect ratio and large flexibly mounted masses distributed along the span. Details of wind-tunnel model supports and balances cover aspects of parameter sensitivity, model wing design, strut and bearing supports and attachments, installation of the vertical supports, and empennage assembly.

New Wind Tunnel Drive Control. G. T. Strailman. *Electrical Engineering*, Vol. 71, No. 7, July, 1952, pp. 648–650, illus.

Construction, operation, and performance of a modified Kraemer wind-tunnel drive in which a liquid rheostat has been added to the rotor circuit permitting maximum speed to be raised to 95 per cent synchronism; comparison with conventional Kraemer wind-tunnel drive system.

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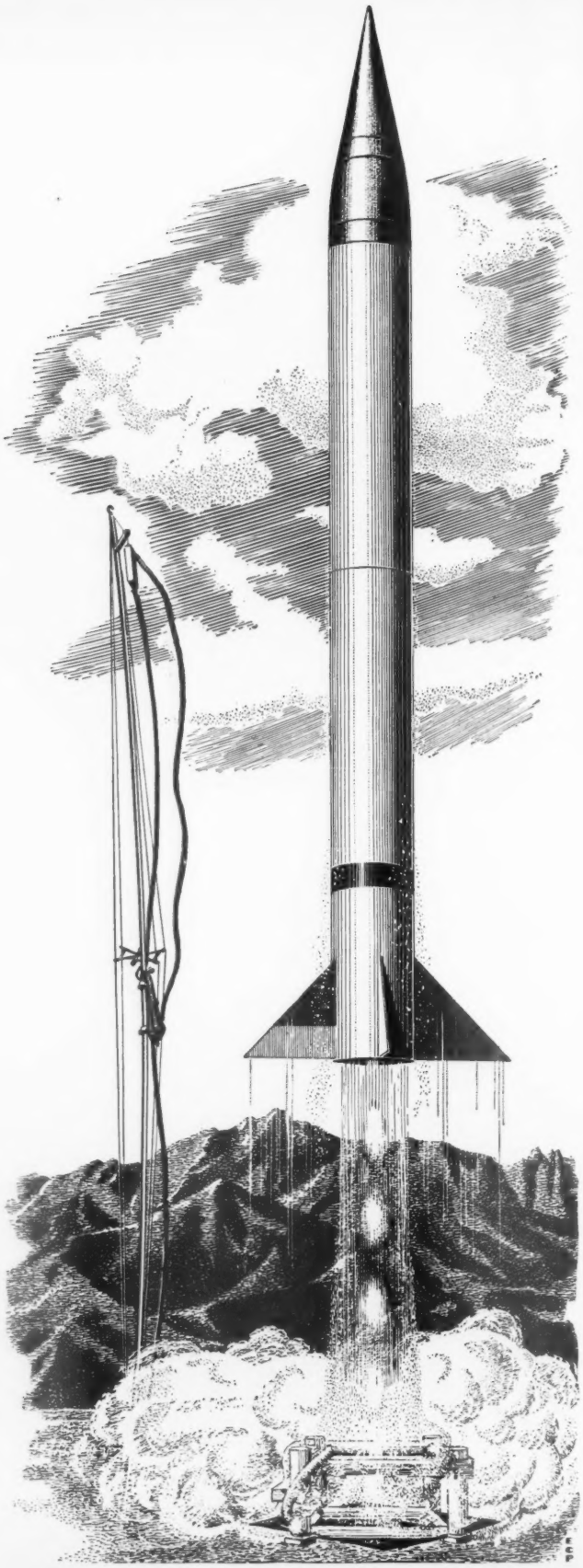

Aeronautical Reviews — BOOKS

Adhesion and Adhesives

Edited by N. A. de Bruyne and R. Houwink. Houston, Texas, Elsevier Publishing Company, 1951. 517 pp., figs. $10.

If you are interested in adhesives, and who in the aircraft industry isn't, this volume is the best ten-dollar investment offered this year. Nothing comprehensive has been published on this subject since the monumental work of Rinker and Kline was put together ten years ago.

The first section, on theoretical aspects of adhesives, takes up the following topics:

Chapter 1, General Conditions for Wetting and for Adhesion, by R. Houwink. Dr. Houwink lays the basic foundations of adhesion in a terse and significant analysis of the conditions that must be brought about. Several examples of surface phenomena are cited. Issue must be taken with talk of hydrophobicity as repulsion of water molecules. It is rather the inability of the surface to overcome the polar attractions of water molecules for each other. This is, in fact, stated in the next chapter.

Particular attention should be directed to the short table of energies required to remove successive layers of water from titanium dioxide crystals. By analogy, this tells the aircraft adhesion engineer something of the nature and magnitude of his surface preparation problems.

Chapter 2, Molecular Forces, by A. J. Staverman. This is an excellent inquiry into the forces that must ultimately hold all organic and polymeric materials together. Induction, dispersion, and ionic or electrostatic forces between molecules are described, and their interactions are considered for organic adhesives. It is emphasized that we are not out of the woods and cannot as yet make precise predictions as to what will give the best adhesion to a particular material.

Chapter 3. Rheology of Adhesives, by J. Hoekstra and C. P. Fritzius The performance of an adhesive is much influenced by its fluidity during cure and its strength and deformation characteristics in service. These topics—the flow and deformation properties—are spoken of as rheology. In this treatment, these factors are considered from the step-by-step breakdown of the bonding operation. Several theories, accounting for the inverse relationship between strength and joint thickness, are discussed. An inquiry into the effects of the ambient operation conditions follows, and the chapter is closed with a few well-chosen words on brittleness.

These first three chapters are required reading for the men responsible for the actual bonding operations.

Chapter 4, Static Problems, by C. Mylonas and N. A. de Bruyne. This chapter, aimed directly at the detail design of bonded joints, is divided into two sections: (1) Theory of stresses in joints and (2) Experimental (photoelastic) verification of these theories. The first part consists of consideration of the strength of various joint designs and the best known theories for explaining these results. Put succinctly, the meaning of this section reduces to "Eliminate Stress Concentrations." Some excellent remarks on the subject of glass-to-metal seals are included here. This is timely in view of the similarity between glass and the resinous adhesives required for strength at the extremes of temperature.

The photoelastic studies of this chapter are most interesting and quite new to American readers. Whether they represent accurately the stress distributions in real adhesive joints is another matter. It is difficult to reconcile the thin bond theory with these photoelastic studies.

Except for the final chapter on testing, the second section of the book is given over to a series of excellent discussions by experts recognized in their fields. These are:

Chapter 5, Organic Adhesives—(a) Animal Glues and their Industrial Applications, by Earl D. Cornwell, Research Division, Armour and Company; (b) Vegetable Adhesives, by William M. Lee, Pennsylvania Salt Manufacturing Company; (c) Synthetic Resin Adhesives, by F. Chapman, Aero Research, Ltd., Duxford, England; (d) Asphaltic Bitumen, by R. N. J. Saal, Koninklijke/Shell-Laboratorium, Amsterdam.

Chapter 6, Inorganic Adhesives and Cements, by John H. Wells, Philadelphia Quartz Company.

Chapter 7, Rubbery Adhesives, by G. Salomon and W. J. K. Schonlau, Rubber-Stichting, Delft, Netherlands.

Chapter 8, Adhesion in Soldered Joints, by W. R. Lewis, Development Manager, Tin Research Institute, Greenford, Middlesex, England.

Chapter 9, The Physical Testing of Adhesion and Adhesives, by N. A. de Bruyne, Aero Research, Ltd., Duxford, England.

These fine expositions on a variety of adhesives give the work a breadth and scope not to be found elsewhere in this field.

A book review can rarely be more than a comparison of the content of the work with the ideas of the reviewer on the topics covered. In most respects the present work rewards the reader by its completeness and by its excellent bibliographies. However, because of the almost complete lack of emphasis on surface chemistry and surface preparation, the reader may be led to believe this is an unimportant matter. Nothing could be further from the truth. This dismissal by omission is the principal weakness of the book. The names of Kasimir Fajans and Linus Pauling do not appear in the index of authors. W. A. Weyl fares scarcely better and the significance of his vital work is not emphasized.

SETH GUNTHORP
Research Engineer, Consolidated Vultee Aircraft Corporation

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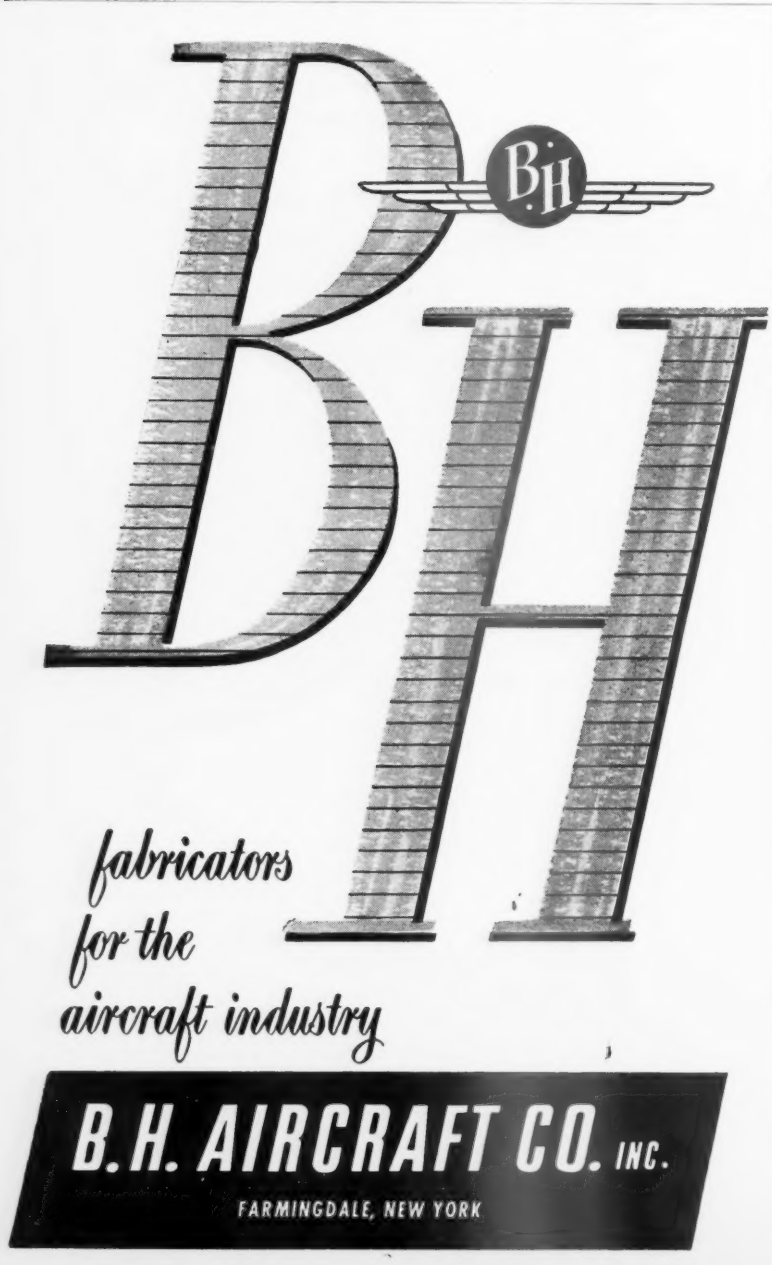
Book Notes

AVIATION MEDICINE

Physics and Medicine of the Upper Atmosphere; A Study of the Aeropause. The Proceedings of a Symposium Held at San Antonio, Texas, November 6–9, 1951, sponsored by the U.S.A.F. Air University School of Aviation Medicine and Arranged by the Lovelace Foundation for Medical Education and Research. Edited by Clayton S. White and Otis O. Benson, Jr. Albuquerque, The University of New Mexico Press, 1952. 611 pp., illus., diagrs., figs. $10.

Contents: Introduction, Clayton S. White. Basic Environmental Problems Relating Man and the Aeropause, A. M. Mayo. Basic Environmental Problems Relating Man and the Highest Regions of the Atmosphere as Seen by the Biologist, H. Strughold. Physical Characteristics of the Upper Atmosphere of the Earth, E. O. Hulburt. Temperatures and Motions of the Upper Atmosphere, William W. Kellogg. Adiabatic Compression and Friction, Fritz Haber. Thermal Aspects of Travel in the Aeropause—Problems of Thermal Radiation, Konrad Buettner. The Chemosphere, Joseph Kaplan. Atmospheric Ozone, Victor H. Regener. Gravity, Inertia, and Weight, Heinz Haber. Meteoritic Phenomena and Meteorites, Fred L. Whipple. Toxicology of Travel in the Aeropause, H. Specht. Solar Physics and the Atmosphere of the Earth, Marcel Nicolet. Ultraviolet Radiation and X-Rays of Solar Origin, T. Robert Burnight. The Nature and Intensity of the Cosmic Radiation, James A. Van Allen. The Biologic Effects of Laboratory Radiation, A. T. Krebs. The Biologic Effects of Cosmic Radiation, Hermann J. Schaefer. Genetic Effects of Cosmic Radiation, H. J. Muller. Discussion of Physics of the Upper Atmosphere, J. Kaplan. Meteoroids, Meteorites, and Hyperbolic Meteoritic Velocities, Lincoln LaPaz. Methods and Vehicles for Research in the High Atmosphere, James A. Van Allen. Plastic Balloons: A Platform for Experiments in the Upper Atmosphere, C. B. Moore. Characteristics of the High-Altitude Rocket as a Research Tool, Homer E. Newell, Jr. The Angular Motion of High-Altitude Rockets, James A. Van Allen. The Return of a Winged Rocket Vehicle from a Satellite Orbit to the Earth, Wernher von Braun. The Physical Recovery of Instruments and Data from a Rocket Flight, Charles P. Smith, Jr. High-Altitude Parachute Recovery, T. W. Knacke. Radio Telemetering, W. J. Mayo-Wells. Methods of Assessing the Biologic Effects of Ionizing Radiation, A. T. Krebs. Cosmic Ray Ionization and the Methods of Measuring It, Edward P. Ney. Known and Predicted Problems of Human Travel in the Aeropause, Paul A. Campbell. Engineering Techniques in Relation to Human Travel at Upper Altitudes, R. M. Salter. Human Orientation During Travel in the Aeropause, Paul A. Campbell. The Effect on Vision Produced by Stimulation of the Semicircular Canals by Angular Acceleration and Stimulation of the Otolith Organs by Linear Acceleration, Ashton Graybiel. A Survey of Present Techniques for Emergency Escape from Aircraft, R. L. Christy. Problems of Escape During Flight Above 50,000 Feet, James P. Henry. A Discussion of the Potential Effects on Man of Ionizing Radiation Present in the Upper Atmosphere, Titus C. Evans. The Biological Effects of Power Plant Radiation, John M. Talbot. Biological Effects of Radiation of Possible Extraterrestrial Origin, Konrad Buettner. Human Tolerance for Temperature Extremes, Craig L. Taylor. Retinal Adaptation Applicable to Visual Problems in Flight at Increasing Altitudes, Paul A. Cibis. Physiological Limitations in Cabin Environment and Human Adaptations, Ulrich Luft. Phasing and Coordination of Medical Research with Technical and Environmental Development, Heinz Haber. Appendix: Conversion Tables. Plates. Combined Index of Subjects and Names Referred to in the Text and in Bibliographies at Ends of Chapters.



ELECTRONICS

Advances in Electronics, Vol. 4. Edited by L. Marton. New York, Academic Press Inc., 1952. 344 pp., diagrs., figs. $7.80.

As in previous years, *Advances in Electronics* continues to present comprehensive reviews on selected topics in electronics in which significant progress has been made. The reviews have been written by experts in the particular fields chosen, and the articles contain references to important contributions to the literature. There is an index of authors cited throughout the book, and a detailed index of subjects.

Contents: Electron Scattering in Solids, H. S. W. Massey, Department of Mathematics, University College, London. The Scintillation Counter, G. A. Morton, Radio Corporation of America, RCA Laboratories Division. Fluctuation Phenomena, Aldert van der Ziel, Department of Electrical Engineering, Institute of Technology, University of Minnesota. Electronic Digital Computers, C. V. L. Smith, Office of Naval Research, Washington. Modulation of Continuous-Wave Magnetrons, J. S. Donal, Jr., Radio Corporation of America, RCA Laboratories Division. The Magnetic Airborne Detector, Winfield E. Fromm, Airborne Instruments Laboratory, Inc. Multichannel Radio Telemetering, M. G. Pawley and W. E. Triest, National Bureau of Standards, Corona, Calif., and International Business Machines Corporation. Author Index. Subject Index.

Flying the Omnirange; A Pilot's Guide to VOR, Distance Measuring Equipment, and the Course-Line Computer. Charles A. Zweng.

North Hollywood, Calif., Pan Americau Navigation Service; Annapolis, Weems System of Navigation, 1952. 128 pp., illus., diagrs., figs. $4.00.

This new revised second edition of a book first published in 1950 is designed primarily to give pilots a practical working knowledge of the new VHF omnidirectional radio range (VOR). The emphasis is placed on the simplicity and ease with which VOR can be used as a navigation aid for cross-country flying and for instrument approaches and letdowns. The book is secondarily a guide to the Instrument Landing System, and it also discusses, from the point of view of the pilot, the two other allied aids that will soon be installed along the Federal airways: distance-measuring equipment and the course-line computer. The contents include a simple description of how VOR works, how it is used for fixing position and flying courses, an account of an actual flight by omnirange, how VOR and ILS are used for instrument approaches and letdowns, and a survey of available omnirange receivers, with current prices. Also included are a number of study questions, with answers, a glossary, index, and large insert map of complete VOR facilities in the U.S. There is also an appendix dealing with the calibration of VOR transmitters and receivers.

Electronic Measurements Manual. C. H. Dunn and H. J. Barker. New York, Prentice-Hall, Inc., 1952. 112 pp., diagrs., figs. $4.35.

This manual has been written to serve as a text for an elementary laboratory course in electrical measurements. Chapter 1 presents an extensive treatment of laboratory techniques; the remainder of the book presents a selection of laboratory experiments. The experiments included may be roughly divided into two categories: (1) the types and characteristics of basic electric instruments, and (2) the use of these instruments in the measurement of electrical and magnetic quantities. Thirty-five experiments have been presented, and most experiments are preceded by a brief discussion. A minimum number of formulas has been given. The authors are Assistant Professors of Electrical Engineering, Rensselaer Polytechnic Institute.

INSTRUMENTS

Strain Gauges; Theory and Application. J. J. Koch, R. G. Boiten, A. L. Biermasz, G. P. Roszbach, and G. W. Van Santen. (Philips Technical Library.) Houston, Texas, Elsevier Press, Inc., 1952. 95 pp., illus., diagrs., figs. $2.55.

The intention of the authors is to provide a concise but comprehensive description of the technique of measuring with strain gages and everything pertaining thereto. The book has been published in joint cooperation between the Netherlands Industrial Organization for Applied Scientific Research (TNO) and N.V. Philips' Gloeilampenfabrieken (Philips Industries) at Eindhoven, Netherlands. This manual has been compiled from many year's experience in the practical use of strain gages and in dealing with those matters that must be known to ensure success in the application of the technique.

Contents: Chapter 1, Construction and Properties of Strain Gauges. Chapter 2, Measuring Instruments. Chapter 3, Technique of Cementing and Connecting Strain Gauges. Chapter 4, Evaluation and Interpretation of the Values Measured with the Aid of Strain Gauges. Chapter 5, Stresses and the Theories of Failure. Chapter 6, Application of Strain Gauges in Measuring Instruments.

MATERIALS

Gmelins Handbuch der Anorganischen Chemie. System No. 41, Titan. (Gmelin's Handbook of Inorganic Chemistry. Vol. 41, Titanium). 8th Ed. Weinheim, Verlag Chemie, G.m.b.H.; New York, Walter J. Johnson, Inc., 1951. 481 pp., figs. $27.20. (In German.)

This Gmelin volume presents a comprehensive, critical, and up-to-date review of the geology, geochemistry, metallurgy, chemistry, physics, and technology of titanium, its alloys, and compounds. The material is presented in such a

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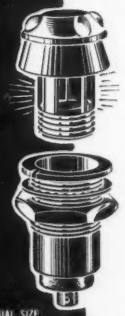

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Early this summer top U.S. Air Force officials met with Civil Defense directors from 46 states and four territories, and reviewed in confidential detail the current efforts to defend America from surprise enemy attack.

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"The only practical means of filling the gaps in our defenses is through a 24-hour operation by civilian volunteers," the meeting was told.

Why isn't America's radar network sufficient?

Defense gaps exists because of radar's line of sight principle, and radar's failure to penetrate opaque masses. Every mountain, every hill casts a shadow behind which enemy aircraft could sneak undetected. Even in perfectly flat country the curvature of the earth shortens the effective range. Equally alarming, radar is susceptible to jamming.

These gaps cannot be filled by Air Force personnel due to the staggering expense. That's why civilians are needed in 27 perimeter states to man Ground Observer Corps stations 24 hours a day. Here is a critical, patriotic job that requires just a few hours a week from each volunteer.

Aircraft too are an important part of our national warning system and of course are the backbone of defense against attack. Three advanced Lockheed planes play a vital role:

The WV-2 *Super Constellation* Early Warning Aircraft, developed for the Navy and the Air Force to extend radar's range in a whole new concept of national defense.

The P2V *Neptune* Navy Patrol Bomber, charged by the Navy with anti-submarine patrol and protection of U. S. coastal waters.

And the F-94C *Starfire*, the nearly automatic all-weather interceptor, which does the final job of climbing to the attack at terrific speed, locating the invaders, and shooting them down with more than human accuracy.

When the U. S. has all necessary planes and personnel—civilian and military—it will be difficult for enemy aircraft to penetrate U.S. defenses.

form as to make it readily available for consultation on any aspect of the subject. The entire pertinent world literature, up to January 1, 1950, is systematically arranged and critically reviewed. A detailed index at the beginning of the volume permits speedy location of information. The work will be of special value to research and industrial workers who wish to avail themselves of the possibilities offered by recent developments in this field.

Contents: History. Occurrence (Geology and Mineralogy). Technical Production of TiO_2 and Production of Titanium Metal. Elemental Titanium. Titanium Alloys. Titanium Compounds.

Gmelins Handbuch der Anorganischen Chemie. System No. 27, Magnesium, Teil A, Lieferung 4, Legierungen von Magnesium mit Zink bis Rhenium, Oberflaechenbehandlung. (Gmelin's Handbook of Inorganic Chemistry. Vol. 27, Magnesium, Part A, Number 4, Alloys of Magnesium with Zinc to Rhenium, Surface Treatment.) 8th Ed. Weinheim, Verlag Chemie, G.m.b.H.; New York, Walter J. Johnson, Inc., 1952. 336 pp., figs. $23.81. (In German.)

This part completes the Gmelin volume on magnesium. It covers binary and ternary alloys from Mg-Zn to Mg-Re as well as surface treatment of Mg and Mg alloys. Thirty-one binary and 105 Mg alloy systems of higher order are treated, for which the following material is given: phase diagrams, data on intermetallic compounds, production processes, casting methods, structural data, and hardening characteristics as well as crystallographic, thermic, optical, electric, magnetic, and electrochemical properties. Chemical behavior and corrosion resistance are covered in detail. For the first time in the literature, this volume presents in a systematic manner the many surface treatment processes and methods used by the industry. The material includes chemical and electrochemical treatment methods, metallic coating and other surface treatments applied to Mg alloys. Of equal importance to scientists and engineers, this volume provides an indispensable source of information on magnesium and its alloys.

MISSILES

Development of the Guided Missile. Kenneth W. Gatland. New York, Philosophical Library, 1952. 133 pp., illus., diagrs., figs. $3.75.

The substance of this book was originally published as a series of articles in *Flight* during the summer of 1951. The manuscript has been fully revised, and opportunity has been taken in the Introduction to include a commentary on the problems of defense against the long-range supersonic rocket. Certain new information is given on rocket armament for aircraft, and tables of data listing 90 guided missiles are found in the Appendix. In addition to information on the development of guided weapons in Britain, the United States, Germany, and the U.S.S.R., the book presents a discussion of satellite vehicles and space ships. The author is an aircraft design engineer and a founder member of the British Interplanetary Society.

Contents: Foreword. Author's Preface. Introduction. Chapter 1, The New Armament. Chapter 2, Air-to-Air Missiles. Chapter 3, Problems of the Supersonic Rocket. Chapter 4, Rockets for High-Altitude Vehicles. Chapter 5, Space-Satellite Vehicles. Chapter 6, Interplanetary Flight. Appendix: Table of Significant Powered Missiles. Subject and Name Index.

POWER PLANTS

Aircraft Propulsion Powerplants. Lawrence T. Cargnino and Clifford H. Karvinen. St. Louis, Educational Publishers, Inc., 1952. 591 pp., illus., diagrs., figs. $6.50.

Aircraft Propulsion Powerplants has been written to provide the background that will enable the student maintenance engineer and the aircraft engine mechanic to explore and grasp with greater clarity the facts pertaining to the more

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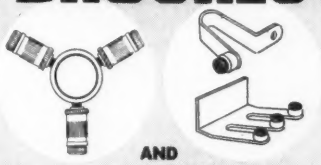
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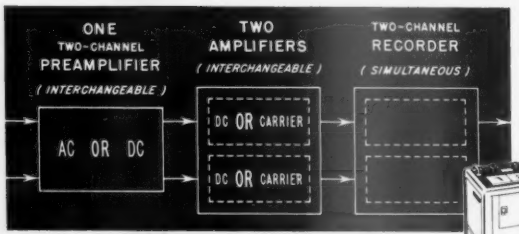

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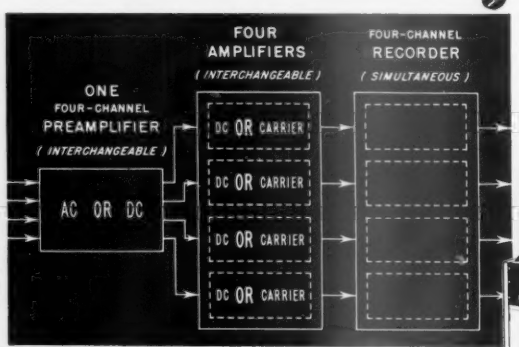

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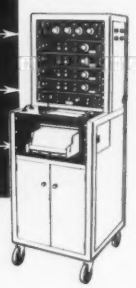

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involved aspects of the airplane engine and its operation. This book stresses fundamentals and operating principles. It is intended to give the reader a foundation not only in all phases of engine and accessory design, construction, and operation, but also in those systems that are related to the operation of the engine. No attempt has been made to give detailed information about specific makes and models of engines, engine accessories, and related equipment, except where such information can be used to enhance the reader's understanding of the topic under discussion.

The book should be of value to mechanics studying for their C.A.A. aircraft engine mechanics rating, to instructor personnel teaching aircraft engine subjects, to students studying aviation subjects in technical high schools, to students in colleges offering aeronautical and mechanical training, and to aviation personnel in general as a convenient reference manual. A particular feature of the book is the more than 500 illustrations and diagrams. Questions are given at the ends of chapters. Cargnino is with Purdue University, and Karvinen is with Parks College of Aeronautical Technology, St. Louis University.

Contents: Engine Theory. Engine Power and Power Measurement. Engine Types, Cylinder Numbering and Firing Orders. Construction Principles of Crankcase and Cylinder Assemblies. Internal Parts of Reciprocating Engines. Induction Systems and Superchargers. Fuels and Fuel Systems. Lubricants and Lubrication Systems. Basic Carburetion. Pressure Carburetors and Mechanical Fuel Injection. Elements of Electricity. Aircraft Engine Ignition Systems. Principles of Batteries, Generators, and Motors. Generator and Motor Control Systems. Powerplant Installation. Engine Control Systems and Engine Instruments. Inspection, Operation and Trouble Shooting. Engine Overhaul, Repair, and Servicing. Propellers. Hydraulically Operated Counterweight Propellers. Hydromatic and Electric Constant Speed Propellers. Jet Propulsion Powerplants. Index.

REFERENCE WORKS

Aircraft Year Book, 1951. Official Publication of The Aircraft Industries Association of America, Inc. Editors: Fred Hamlin, Arthur Clawson, Eleanor Thayer, and Robert McLarren. Washington, Lincoln Press, Inc., 1951. 464 pp., illus., diagrs. $6.00.

The thirty-third annual edition of this standard reference work presents a comprehensive review of events and developments in military and civil aviation in the United States during the year 1951. The plan of the previous volumes is maintained: outstanding technical developments in the design, manufacturing, and research fields are described; aircraft in production during 1951 are described in detail, with photographs and three-view drawings; and brief biographies of 1,200 aviation personalities are presented. The *Year Book* is compiled entirely from material prepared by industry.

Contents: Aviation Books Published in the United States in 1951. Summary Statistics. The Industry. Department of Defense. Technical Progress. The Government and Aviation. The Airlines. Personal Aircraft and Helicopters. Planes in Production. Engines in Production. 1951 Day by Day Chronology. Biographical Briefs. A Chronology of U.S. Aviation. Official Records. Index.

French-English Science Dictionary; For Students in Agricultural, Biological, and Physical Sciences, with a Supplement of Terms in Aeronautics, Electronics, Radar, Radio, Television. Louis De Vries. 2nd Ed. New York, McGraw-Hill Book Company, Inc., 1951. 596 pp. $6.50.

This volume has been enlarged to make it of greater value to all users by the inclusion of a supplement of terms that have come into our vocabulary in the last 10 years as a result of recent developments in aeronautics, electronics, radar, radio, and television. The first edition, published in 1940, contained some 43,000 entries. Preceding the vocabulary is a list of useful dictionaries and reference works. The book concludes with a

twelve-page list of abbreviations. De Vries is Professor of Modern Languages, Iowa State College.

SCIENCES, GENERAL

MATHEMATICS

Dictionary of Conformal Representations. H. Kober. New York, Dover Publications, Inc., 1952. 208 pp., diagrs. $3.95.

The present book contains a collection of formulas and properties of a number of conformal representations, classified according to the analytic functions describing the transformations. No proofs are given; however, in Part IV, the method of the Schwartz-Christoffel transformation is explained. Most transformations are illustrated by pairs of diagrams that show corresponding curves and corresponding regions; there are 447 diagrams in all. The volume should be helpful in hydrodynamics, gas dynamics, free streamline theory, heat flow, magnetic field problems, soil mechanics, electrostatics, and map projection. Specific features contained are: linear and bilinear transformations for electrical engineers, Joukowski airfoil for aerodynamicists, transcendental functions for physicists and engineers; Schwartz-Christoffel transformations for hydrodynamicists and electrical engineers, and Borda's mouthpiece for researchers in hydraulics and jet propulsion. This dictionary was written for the British Admiralty during 1944–1948 in five separate parts that were reproduced and circulated in the Department of Scientific Research and Experiment and in the Department of Physical Research. References to fuller treatments in the literature are given occasionally in the text.

Contents: Notations and Nomenclature. Part I, Linear and Bilinear Transformations. Part II, Algebraic Functions and z^{α} for real α. Part III, $w = e^{z}$, $w = \log z$ and related functions. Part IV, Schwartz-Christoffel Transformations Representable in Terms of Elementary Transformations. Part V, Higher Transcendental Functions. Main List of References. Topological Subject Index.

Calculus of Variations with Applications to Physics and Engineering. Robert Weinstock. New York, McGraw-Hill Book Company, Inc., 1952. 326 pp., figs. $6.50.

This book illustrates the application of the calculus of variations in several fields outside the realm of pure mathematics. In addition to a brief treatment of the classical elementary problems, the work contains sections involving the role of the calculus of variations in particle dynamics, geometric optics, quantum mechanics, elasticity, and electrostatics and in the eigenvalue problems associated with the vibrating string and vibrating membrane. Techniques and underlying ideas are emphasized. The δ method is avoided throughout. The author demonstrates the manner in which application of the calculus of variations to a specific physical problem leads to not only the differential equation but also the boundary conditions associated with the problem. A distinction is made between "imposed" and "natural" boundary conditions. Other features include: a detailed exposition of Courant's maximum-minimum principle; application of the Ritz method for approximating the few lowest eigenvalues; and development of the role of calculus of variations in quantum mechanics. Many valuable exercises are included which help fill in details, illustrate methods, and extend the results achieved in the text. The author is Acting Assistant Professor in Mathematics, Stanford University.

Contents: (1) Introduction. (2) Background Preliminaries. (3) Introductory Problems. (4) Isoperimetric Problems. (5) Geometrical Optics—Fermat's Principle. (6) Dynamics of Particles. (7) Two Independent Variables: The Vibrating String. (8) The Sturm-Liouville Eigenvalue-Eigenfunction Problem. (9) Several Independent Variables: The Vibrating Membrane. (10) Theory of Elasticity. (11) Quantum Mechanics. (12) Electrostatics. Bibliography. Index.

MECHANICS

Mechanics. Part 1, Statics. Part 2, Dynamics. J. L. Meriam. New York, John Wiley & Sons, Inc., 1952. 2 Vols. 340, 671 pp., diagrs., figs. $4.00 per Vol.

These two volumes have been written as texts for basic mechanics courses in the normal engineering curriculum. A total of 1,272 problems for solution by the student has been included which have been drawn from various fields of application. Almost all of the problems have been illustrated by line drawings in which clarity and reality are stressed.

Statics, the first volume, begins with an overall introduction to the field of mechanics and progresses from force systems through equilibrium. Emphasis is on the relatively few principles that govern all cases rather than on detailed differentiation of special cases. The coverage of statics is broadened by the treatment of shear and moment distribution in beams and by a rigorous presentation of the method of virtual work leading to the important energy criterion for equilibrium.

The second volume, *Dynamics*, follows a similar pattern and emphasis. Kinematics is treated separately from kinetics, but for easy reference the study of motion is divided into the same categories used in the chapter on force, mass, and acceleration. Emphasis is on the direct use of the equations of motion, although the inertia-force method is described and used alternately. The work-energy chapter stresses the type of problem for which this method is superior to the other by use of the force-mass-acceleration equations. The treatment of impulse and momentum leads to the interesting subject of variable mass which is illustrated with problems on rocket and jet propulsion. An introduction to mechanical vibrations and other cyclic motions is presented in the last chapter on periodic motion. The author is Associate Professor of Engineering Design, University of California.

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The Experimental Approach to Aircraft Structural Research, P. B. Walker (Fifteenth Wright Brothers Lecture reprinted from the March, 1952, and April, 1952, JOURNAL OF THE AERONAUTICAL SCIENCES)	1.00	1.50
The Earth's Atmosphere, H. E. Roberts, including 20- by 16-in. colored chart (Reprinted from the October, 1949, AERONAUTICAL ENGINEERING REVIEW)	0.65	1.00

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Mechanical Engineers—Army Ordnance Design. Engineering ability to make original layouts and calculations required in the design of aircraft and ground-type rocket and missile launchers, aircraft and ground-type artillery and small arms weapons, and the mechanisms and control units involved, such as hydraulic and electrical power systems, structural elements, linkages, cams, gear trains, etc. GS-11, $5,940 per annum—bachelor degree plus 2½ years' progressive professional engineering experience, including at least 6 months of difficult and important work in the appropriate branch of engineering equivalent in grade level to that required of GS-9 engineers; GS-9, $5,060 per annum—degree plus 1½ years of progressive professional engineering experience, including at least 6 months' work in the appropriate branch of engineering equivalent in grade level to that required of GS-7 engineers; GS-7, $4,205 per annum—degree plus 6 months of professional engineering experience in the appropriate branch of engineering. Lacking degree, combination of education and experience permitted. Applicants should submit Standard Form 57, Application for Federal Employment (available at any Post Office), to: Personnel Division, Rock Island Arsenal, Rock Island, Ill.

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